RTO-34B Final Report

Inter-sector Planning

En Route Controllers Roles, Responsibilities, and Procedures

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June 9, 2000

Executive Summary

Trajectory orientation is a procedural concept that enables en route controllers to plan and coordinate trajectories across sector boundaries while efficiently maintaining separation and conforming to flow-rate constraints. Today's sector-oriented procedures are characterized by an emphasis on controller actions to protect their sector's internal airspace. In contrast, a trajectory orientation emphasizes controller actions that work cooperatively across sectors and depend on each other for well-planned, nominally conflict-free flow of traffic. As an alternative to the technical modernization of current practices, a trajectory orientation represents the operational goal for which decision support technology should be developed. An en route operations assessment, including a literature review and structured interviews with controllers from the Cleveland and Denver Centers, was conducted to determine the core issues that inhibit a trajectory orientation in today's operational environment. Results indicated that the most significant problem was the controller's inability to perform accurate strategic planning. This problem was decomposed into low-level issues that can be solved using a combination of Free Flight technology currently being researched and new procedures. In addition, several concepts for new controller roles, responsibilities, and procedures were evaluated for their potential in achieving a trajectory orientation. Two concepts, one inspired by the EUROCONTROL multi-sector planner and one based on the Upstream Team, were determined to be most likely candidates for achieving a trajectory orientation. The Upstream Team concept was inspired by operational CTAS/EDA and is similar to the AERA 2 operational concept.

1 Introduction

In support of Free Flight, many new tools and technologies are being developed to improve the efficiency of the National Airspace System (NAS) through evolutionary enhancements. Automation enhancements to current practices will offer immediate benefit. However, the greatest potential for improvement will come from new practices and procedures enabled by new decision support tool (DST) technologies. A case in point is the En route Descent Advisor (EDA), a Center-TRACON Automation System (CTAS) DST under development at the NASA Ames Research Center (Reference 1). EDA assists controllers with the separation and flow-rate conformance (i.e., time-based metering and/or distance-based spacing) of air traffic in en route airspace. Although utilization of conflict probe and metering tools within today's "sector-oriented" operational paradigm will provide some Free Flight benefits, significantly greater benefits would be realized by a shift to a "trajectory-oriented" operational paradigm. This is the goal for developing EDA.

Trajectory orientation is a procedural concept that enables en route controllers to plan and coordinate trajectories across sector boundaries while efficiently maintaining separation and conforming to flow-rate constraints (i.e., time-based metering and/or distance-based spacing). This concept facilitates efficient inter-sector planning envisioned by Free Flight proponents[*] through new en route controller roles, responsibilities, and procedures.

The content of this report focuses on presenting the trajectory orientation concept, identifying issues in today's operations that inhibit it, and suggesting solutions to enable it. In the following section, EDA is discussed sufficiently to highlight DST capabilities necessary to support trajectory orientation. This is followed by a detailed overview of the trajectory orientation concept. The remainder of the paper (Sections 4-9) is the research that supports the research task order (RTO) 34 and 34B statements of work. The results of RTO-34 and RTO-34B are combined here into one final report. The primary purpose of the RTO-34B extension work was to gain further insight into strategic planning of flow-rate conformance constraints and DST capability and usability requirements. Readers should take note that some of the results from RTO-34 final report have been revised based on research performed during the RTO-34B period of performance. *As such, this report supersedes the RTO-34 final report and should be the sole reference with respect to either RTO.*

2 Background

EDA or EDA-like DSTs are the primary enabling technologies that make trajectory orientation possible. EDA (Reference 1) will enable controllers to more easily accommodate user-preferred trajectories while efficiently assuring traffic separation and conformance with flow-rate restrictions. EDA will accurately detect separation and flow-rate conformance problems up to 20 minutes into the future (generally across 1-2 sectors). The CTAS trajectory-prediction accuracy

[*] This is also a fundamental step toward both the trajectory negotiation and free maneuvering distributed air/ground concepts in Reference 4.

that supports such advisories has undergone extensive field-testing and validation (References 2-3). The controller is also provided with resolution advisories that are nominally problem-free over a 20-minute time horizon (i.e., conflict-free and in conformance with air traffic control (ATC) constraints such as required time of arrival, spacing restrictions, and crossing restrictions).* Trial planning capability allows the controller to direct EDA advisories according to their own operational preferences. A significant economic and workload benefit will be enabled by EDA's capability to develop path-independent flow-rate conformance advisories. Instead of forcing flow-constrained flights in trail to establish spacing, EDA allows controllers to delay merges and minimize deviations from user-preferred trajectories. This approach reduces the concentration of metered flights in any one sector thus distributing the workload across sectors and away from the final merge point.

EDA and the trajectory orientation concept mesh well with the NASA Advanced Air Transportation Technologies goal of developing longer-term technologies that will support user flexibility and distributed air-ground (DAG) traffic management (Reference 4). EDA will provide controllers with the decision support needed to manage a Free Flight environment characterized by:

- Significant reduction in procedural restrictions
- Significant increase in dynamically-imposed flow restrictions (to mitigate capacity overloads)
- Significant increase in dynamic flight replanning by the user

The long pole in the tent is the challenge of transitioning flights to/from high-density terminal areas. Economically, it does not make sense for the user/ATC community to heavily invest for en route savings only to lose those benefits upon transition to a congested airport. Many concepts, ranging from "trajectory negotiation" to "free maneuvering." have been proposed to maximize user flexibility in en route airspace. In any case, the EDA/trajectory orientation combination may be viewed as an enabling step to "transition" Free Flight aircraft smoothly and efficiently to and from the terminal area.

3 The Trajectory Orientation Concept

Trajectory orientation is a concept, developed at NASA Ames Research Center (Reference 1), is proposed as an alternative to today's sector-oriented ATC operations. Trajectory orientation requires a fundamental shift in thinking about inter-sector coordination.

Today's sector-oriented operations are characterized by controller emphasis on actions to protect their sector's internal airspace. The primary focus is on the planning and tactical separation of aircraft within their sector. This planning also includes consideration for constraints, such as crossing restrictions, both within the sector and within close proximity to the sector boundary (to

* The key to EDA is the integration of flow-rate conformance and conflict detection and resolution (CD&R) advisories. Integration not only reduces conflict-probe false-alarm and missed-alert rates when needed most (under high-density delay conditions), it leads to more-efficient traffic plans that are nominally conflict free.

facilitate a hand-off to the next sector). The hand-off process is used to ensure that incoming flights are at least tactically separated. However, there is little visibility or control over the conformance of incoming flights with flow-rate restrictions. The sector closest to flow-restricted airspace not only has the greatest concentration of impacted flights, but also the greatest potential responsibility for conformance. Sector-oriented operations generally involve just enough cooperation between adjacent sectors to permit a handoff, but not enough to achieve an efficient flow of traffic.

Trajectory orientation, on the other hand, focuses on efficient flight planning that nominally conforms to all ATC constraints within a time horizon (e.g., 15-20 minutes) independent of airspace boundaries. In addition to separation, this approach emphasizes the upstream strategic planning of actions to conform to flow-rate restrictions in downstream sectors. The result is a distribution of workload away from the flow-impacted airspace. Instead of controllers operating relatively independently, with the main focus on protecting their sector's internal airspace, the controllers would work cooperatively across sectors and depend on each other for a well-planned flow of traffic.

Trajectory orientation will require new roles, responsibilities, and procedures for en route controllers that could potentially be quite different from today's operations. Trajectory orientation is the ATC counterpart to the orientation of a pilot in operating his/her aircraft. Pilot actions not only consider their current state and tactical challenges (e.g., weather and traffic avoidance), but also their strategic goal to complete the trajectory (i.e., they maintain a continuously updated trajectory plan for completion of the flight).

Two example cases are presented next to illustrate two specific differences between sector-oriented and trajectory-oriented operations. Figure 1 depicts a sector orientation for the first case. In this example, the aircraft in Sectors 1 and 2 are compliant with all constraints within their respective sectors as well as any Sector 3 handoff constraints. However, to solve a downstream capacity problem, traffic management requires a 20 nm spacing at the Sector 3/4 boundary for aircraft A, B, and C. This restriction corresponds to an approximately 20-minute time horizon from their current positions in sectors 1 and 2. In today's environment, the delay maneuvers for spacing conformance would most likely occur in Sector 3, the downstream sector. This is illustrated in Figure 1 by the vector deviations to aircraft A and C within Sector 3 airspace.

Figure 2 illustrates the trajectory-oriented version of the first example. In this case, the delay maneuvers to meet the spacing requirements would occur in the upstream sectors. The longer time horizon allows the upstream sectors to better utilize speed control to achieve most, if not all, of the spacing requirement. Any excess delay can be absorbed with efficient, strategically planned path-stretching. Additional action by the downstream controller (Sector 3) is only needed to adjust for unplanned disturbances (i.e., actions required by exception rather than the rule).

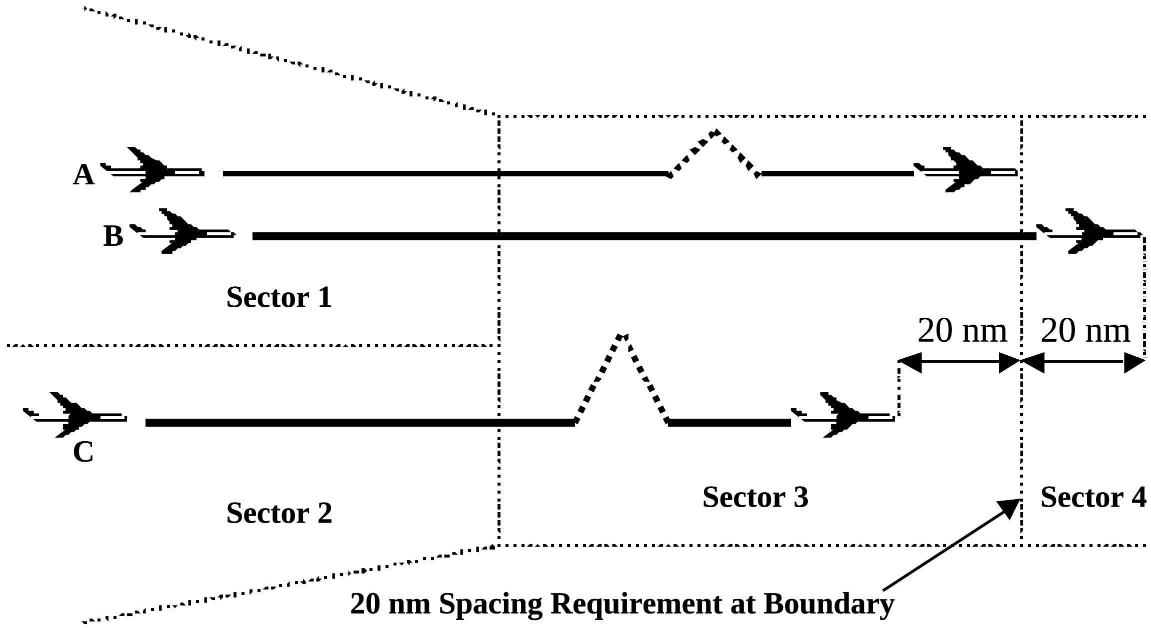

Figure 1. Sector Orientation Example #1

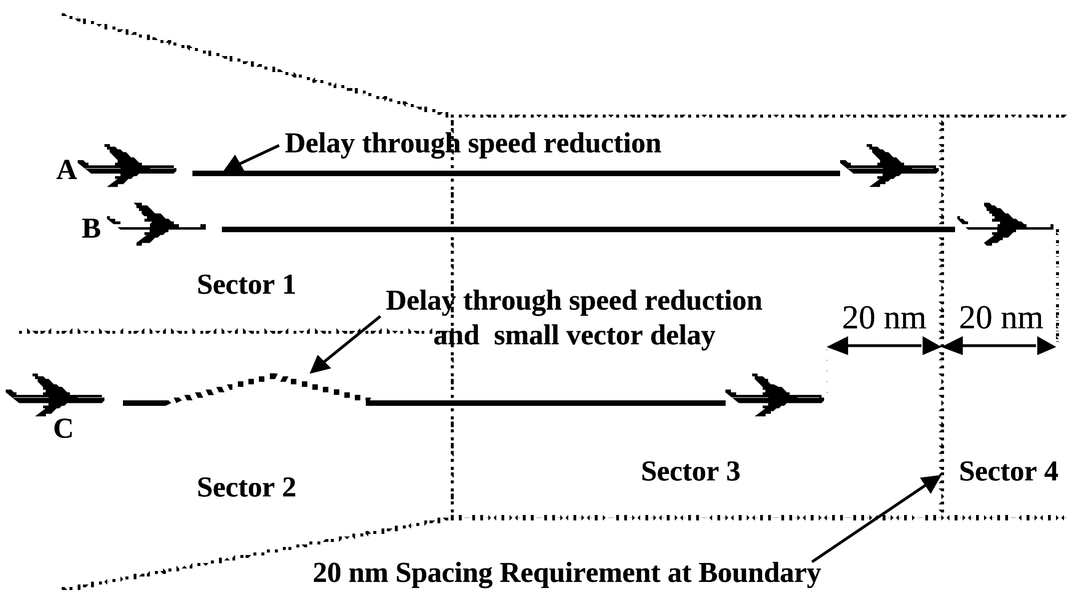

Figure 2. Trajectory Orientation Example #1

Figure 3 depicts a sector orientation for the second case. For this example, traffic management still requires a 20 nm spacing at the Sector 4 boundary. However, they also “pass back” a spacing restriction of 40 miles in trail at the Sector 1/3 and 2/3 boundaries to assist the Sector 3 controller with absorbing the required delay for the final spacing at the Sector 3/4 boundary. In this example, the Sector 1 controller must delay aircraft A 35 nm to achieve the 40 nm spacing at the Sector 1/3 boundary. However, this is an unnecessary delay because there are no aircraft in Sector 2 that must be spaced between aircraft A and B. In fact, aircraft C is the only aircraft in Sector 2 during this time period and because it is ahead of the aircraft in Sector 1, aircraft C requires no delay at all. If the controller in Sector 1 was aware of this, he/she could have delayed aircraft A 15 nm instead of 35 nm. As such, Aircraft A crosses the Sector 3/4 boundary with 16 nm of excessive spacing

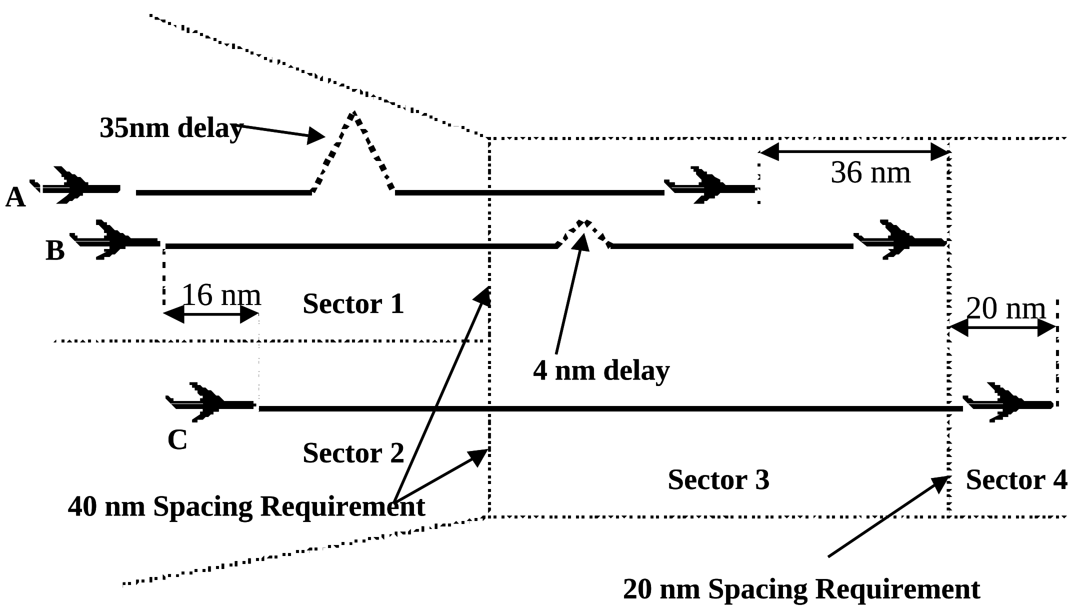

Figure 3. Sector Orientation Example #2

In Figure 4, DST technology enables upstream controllers to determine the accurate relative spacing between aircraft in adjacent sectors due to downstream constraints. This allows the controllers in Sectors 1 and 2 to effectively coordinate downstream spacing while maximizing the independent operations of both sectors (Reference 5). Because of this capability, traffic management would not need to artificially pass back spacing requirements to the upstream sectors. This prevents inefficient gaps or missed slots that prevent airspace from being used to its true capacity.

Although not explicitly depicted in Figure 3, the pass back procedure commonly used by traffic management highlights another problem. Pass back procedures rarely result in a seamless transition of merging streams for the downstream controller. Using the sector geometry and traffic management constraints depicted in Figure 3, a seamless transition requires a projected spacing of 20 nm in the downstream sector (i.e., Sector 3) between aircraft currently positioned in Sector 1 and Sector 2 in addition to 40 nm between aircraft in the same sector. In other words, even if the aircraft in a given sector are each appropriately spaced relative to other aircraft in that sector, anything other than a projected 20 nm “relative” spacing between aircraft in Sector 1 and aircraft in Sector 2 would require the Sector 3 controller to delay one of the streams to achieve the final spacing.

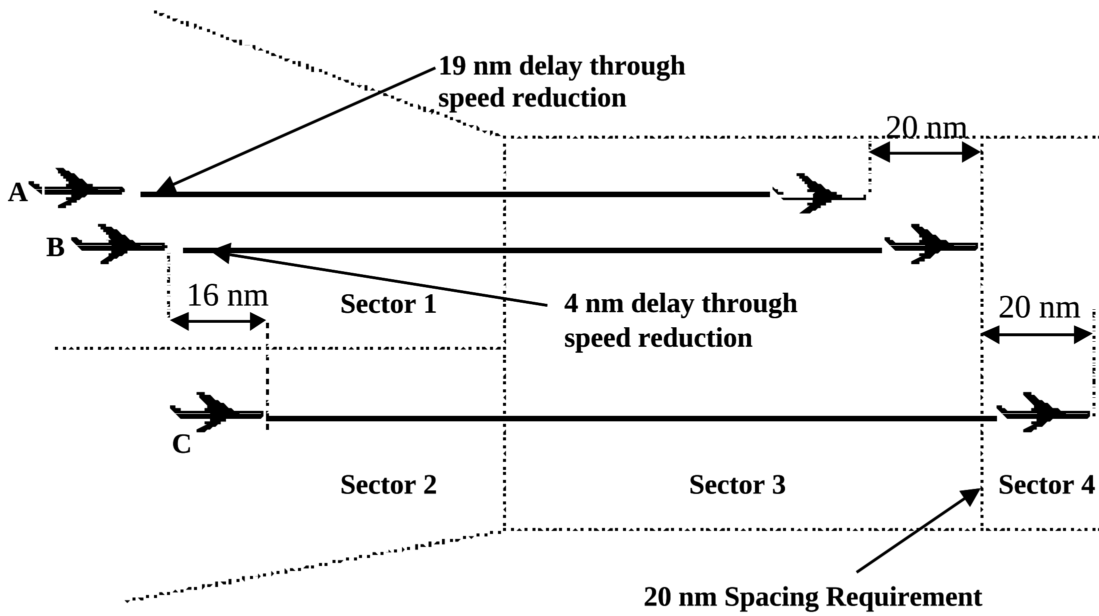

Figure 4. Trajectory Orientation Example #2

The problems with the pass back procedures as described above can be solved with a transition toward a time-based metering environment. This is because flow conformance of aircraft due to metering is measured relative to time rather than to other aircraft. However, even with meter-fix delay times displayed on an upstream sector’s display, the tactical and gross nature of today’s techniques and procedures leaves the upstream controller ill-equipped to plan the actions necessary to accurately absorb the required delay. The downstream controller must then plan new actions to meet the required metering times. Ironically, the potential elegance and efficiency of metering is hardly realized with today’s imprecise delay tactics and procedures.

In summary, the strategic nature of trajectory orientation offers several advantages when supported by DST technology. The efficiency of flow-rate conformance (delay absorption) is increased in three ways. First, the strategic planning reduces the need for tactical corrections (interruptions) since each maneuver action is calculated to nominally result in conformance. Second, as depicted in example 1, this approach enables greater use of speed control by increasing the time horizon for conformance. Third, as depicted in example 2, excessive spacing between aircraft can be significantly reduced because DST functionality provides relative spacing information between aircraft in adjacent sectors. With respect to workload, as depicted in both examples, trajectory orientation results in a more even distribution of workload from the downstream sector (where traffic is converging) to sectors further upstream.

Although the examples presented above are useful in describing a trajectory orientation, they only focus on the aspects related to inter-sector coordination. The other key aspect, “where the rubber meets the road,” relates to the complementary subject of intra-sector coordination. The operational roles and responsibilities of individual controller positions (e.g., radar (R-side) and radar associate (D-side)) define the building blocks from which inter-sector procedures may be created. Evaluating these roles and responsibilities is the primary objective of this research. The results of this evaluation are discussed in the section on Evaluation of Candidate Controller Roles, Responsibilities, and Procedure.

4 Research Approach

The top-level objectives of RTO-34/B were:

1. Determine the core issues in today's en route operations that inhibit a trajectory orientation.
2. Identify potential technology and procedural solutions that address those issues.
3. Evaluate specific candidate concepts to determine which have the highest potential of achieving a trajectory orientation in preparation for more focused evaluations via high-fidelity controller-in-the-loop simulation.

The first step in meeting the objectives was to perform an assessment of today's en route operations. The assessment included a literature search of current en route operations. In addition, future Free Flight concepts were researched because of their potential impact on current operations. In just the last 3 years, three books (references 6-8) have been published on human factors issues in air traffic control (ATC). These books are essentially compilations of the latest ATC research with a focus on how new technology and higher levels of automation could impact human operators.

In the RTO-34 proposal, it was stated that a high-level task analysis of current en route controller roles, responsibilities, and procedures would be performed as part of the operations assessment. However, the above-mentioned literature search indicated the FAA’s Civil Aeromedical Institute had already prepared a thorough task analysis in 1993 (reference 9). A comprehensive evaluation of the FAA task analysis, referred to as a job task taxonomy in Section 5.1, determined that this analysis was more than sufficient in meeting the needs of this research.

Together, the FAA task analysis and the other information collected from the literature search provided the necessary background to approach a group of subject matter experts to address the RTO-34 objectives. Permission was granted from the regional division of the FAA and the national and local offices of the National Air Traffic Controllers Association to have access to en route controllers from the Denver Center. The Denver Center was chosen because of the close proximity to the offices of the principal researcher. Two groups of controllers, consisting of three controllers each, participated in the study. The collective en route experience of the two groups was about 100 years. All the controllers had been hired since the 1981 controller strike. One controller was very experienced with the CTAS. Two other controllers had some experience with CTAS. CTAS experience is mentioned here because a major component of EDA (formally referred to as the Descent Advisor) is one of the core CTAS tools.

To take full advantage of the controllers' expertise, the format of the two controller working group meetings were slightly different. Both meetings began with an overview of the trajectory orientation concept. This was followed by a demonstration of the CAST simulation. The CAST simulation was developed by NASA in the early 1990s and represents much of the functionality that will be present in EDA. The interface is somewhat obsolete, but the algorithms for conflict detection and resolution (CDR), spacing and metering give the viewer a high fidelity illustration of EDA features. After the demonstration, the first group was asked questions about current procedures related to CDR and flow-rate conformance and techniques that inhibit a trajectory orientation. This was followed by questions on EDA usability and capability. Finally, the first group was asked to discuss the advantages and disadvantages of the candidate concepts outlined in the SOW.

The format for the second group was changed slightly based on lessons learned from the first group. Most of the first group's responses to questions about current operations reflected what had already been learned through the literature review. On the other hand, the first group had very strong opinions about the candidate concepts that the author had not anticipated. Based on this, the second group was asked to discuss the candidate concepts immediately after the CAST demonstration. (As an immediate ramification of the controllers' input, an additional candidate concept was added to the list of concepts for evaluation (see Section 7.7)). Late in the day, after the candidate concept discussion was completed, EDA usability and capability issues were identified. Both groups of controllers were quite appreciative of the opportunity to be involved in the meetings. All the controllers indicated that they would willingly participate in future discussions if necessary.

For RTO-34B, there was a need to collect information from controllers in other Centers to gain another perspective on trajectory orientation inhibitors and ensure robust solutions. Cleveland Center was chosen because of the complexity of the air traffic it manages on a daily basis. Located between Chicago and the Northeast Corridor, it is the busiest Center in the USA with over 2.6 million operations in 1999 (Reference 10). Each sector within Cleveland Center must handle a complex mixture of arrival, departure and over-flight traffic on a regular basis.

Because strategic planning with respect to flow-rate conformance constraints is particularly important to this research, the visit to the Cleveland Center included one day with personnel in the traffic management unit (TMU). Again, the EDA/trajectory orientation concept was presented, but this time without the aid of the CAST demonstration (because of transportability of the Sun SPARC10 computer and monitor). Viewgraphs and screen shots of the CAST demo were used instead. The group consisted of six members from the TMU (three coordinators, one specialist, and two managers). Throughout the day, the principal researcher observed three different coordinator (i.e., TMC) positions to learn their roles in traffic management and strategic planning. The following day, three controllers (one of whom is a NATCA representative for the National Airspace Re-design), representing three different areas of Cleveland Center airspace, participated in controller interviews similar to the one with the second group of Denver Center controllers. However, because a down-selection process for controllers roles and responsibilities was performed during RTO-34, only the down-selected candidates (see Section 7.8) were presented to the controllers. Again, the meeting was well received and in particular, TMU personnel made strong requests that an EDA prototype be delivered to Cleveland Center for development and testing.

The information collected from the controller interviews and literature review was organized to clearly address the RTO-34 and 34B objectives as described in Sections 5-9 below.

5 Results of the Operations Assessment

5.1 Controller roles and procedures in today's operations

The first step in the operations assessment was to understand the tasks and procedures performed by en route controllers. The FAA air traffic control handbook (reference 11), 7110.65, provides a comprehensive description of controller responsibilities and the resulting procedures for en route, terminal, and tower airspace. 7110.65 (known as the 'seventy-one ten' by controllers) is a very useful document for describing the necessary procedures that should be performed in any given situation.

A general outline of the primary en route R-side and D-side responsibilities, as they exist today, is referenced from 7110.65. Statements in parenthesis are clarifications by this author of the implications of the 7110.65 as it applies to this research.

R-side:

- Ensure separation (using radar information as the primary means)
- Initiate control instructions (for separation and other sector functions such as meeting dynamic traffic management constraints or static flow restrictions)
- Monitor and operate radios
- Accept and initiate automated handoffs
- Assist the D-side position with non-automated handoff actions when needed
- Assist the D-side position in coordination when needed
- Scan radar display. Correlate with flight progress strip information
- Ensure computer entries are completed on instructions or clearances you issue or receive (it should be noted that in today's operations this procedure does not guarantee good intent. There are instances where clearances to aircraft do not require flight plan amendments, but intent is still needed for accurate DST predictions. Examples include aircraft placed in holding

patterns, temporary speed or vector changes that do not result in downstream flight plan changes.)

- Ensure strip marking is completed on instructions or clearances you issue or receive
- Adjust equipment at R-side to be usable by all members of the team
- The R-side shall not be responsible for G/G communications when precluded by VSCS split functionality

D-side:

- Ensure separation (primarily through the use of flight strips for aircraft entering the sector. In the case of radar display failure, this becomes the primary means for separation of all aircraft “owned” by the sector)
- Initiate control instructions (for upstream aircraft or to assist the R-side)
- Operate interphones (means for coordinating actions with upstream controllers)
- Accept and initiate non-automated handoffs, and ensure radar position is made aware of the actions
- Assist the R-side by accepting or initiating automated handoffs which are necessary for the continued smooth operation of the sector, and ensure that the R-side is made immediately aware of any action taken
- Coordinate, including pointouts
- Monitor radios when not performing higher priority duties
- Scan flight progress strips. Correlate with radar data
- Manage flight progress strips
- Ensure computer entries are completed on instructions issued or received. Enter instructions issued or received by the R-side when aware of those instructions
- Ensure strip marking is completed on instructions issued or received, and write instructions issued or received by the R-side when aware of them
- Adjust equipment at D-side position to be usable by all members of the team

A drawback to the 7110.65 is that it lacks a formal sequence of tasks corresponding to specific controller activities. With respect to this research, the lack of task sequence is particularly apparent for conflict resolution and traffic spacing activities. Fortunately, a literature search revealed that a document written by the FAA Civil Aeromedical Institute (Reference 9) did address the issue of task sequence through a formal job task taxonomy.

This above-mentioned document, *Conversion of the CTA, Inc. En Route Operations Concepts Database into a Formal Sentence Outline Job Task Taxonomy* (referred to as the “Job Task Taxonomy” for the remainder of this report), was derived from an earlier effort (Reference 12) by Computer Technology Associates (CTA). It describes cognitive as well as non-cognitive en route controller tasks to assist with the assessment of contractor proposals for the Advanced Automated System (AAS). The goal of the Job Task Taxonomy project was to convert the rather complex format of the CTA document into an easily understood, well-defined hierarchy of task decomposition that could be utilized for ATC research.

The Job Task Taxonomy defines top-level controller job functions as activities. Sub-activities are the next level and describe work performance actions. The third level, tasks, describes units of work performance. Task elements are the final level of decomposition and describe the most fundamental steps and actions required to complete a task. The Job Task Taxonomy contains 61 pages, 6 activities, 39 sub-activities, 400 tasks, and several hundred independent task elements. The Job Task Taxonomy does not differentiate between R-side and D-side positions. It represents the tasks that would be performed if a single controller was working a sector. Specific D-side roles, as they pertain to this research, are discussed in Section 5.2

Below is a top-level list of controller activities from the Job Task Taxonomy.

Top-level Controller Activities

I) Perform Situation Monitoring
II) Resolve Aircraft Conflicts
III) Manage Air Traffic Sequences
IV) Plan Flights
V) Assess Weather Impact
VI) Manage Sector Resources

The next section (Section 5.1.1) lists the tasks performed by controllers for conflict detection and resolution for en route airspace subject to instrument flight rules. This task list is a composite from two activities listed above, "Perform Situation Monitoring" and "Resolve Aircraft Conflicts." Only a small segment of the "Perform Situation Monitoring" activity was needed to compose a list of tasks associated with conflict detection. A much larger segment of the "Resolve Aircraft Conflicts" activity was needed to compose a list of tasks associated with conflict resolution. In a similar manner, Section 5.1.2 lists the tasks performed by controllers to support flow/flow-rate conformance. This list was composed from the "Manage Air Traffic Sequences" activity.

The activities, tasks, and task elements listed below have been re-numbered from the original Job Task Taxonomy because many tasks not directly related to these activities have been omitted here for reasons of clarity and brevity. The reader should note that the Job Task Taxonomy is not always serial in the ordering of the tasks elements that support a task and likewise, for tasks that support a sub-activity.

5.1.1 Conflict Detection and Resolution

I) Perform Situation Monitoring
  A. Check and evaluate separation
    1. Review the radar display for potential violation of aircraft separation standards
      a. Acquire target symbol, data block, and geographic map data on radar display for potential violations of aircraft separation standards
      b. Acquire route display off aircraft potentially violating separation standards
      c. Synthesize altitude, speed, time, and route/direction of flight into a complete

mental traffic picture with regard to potential violation of aircraft separation standards
    d. Recognize potential violation of aircraft separation standards

2. Project mentally an aircraft's future position, altitude and path
    a. Search the radar display for target symbol and full data block of aircraft in potential conflict for data to project position

    b. Extract obstruction, airspace area, geographic map data, (i.e. minimum vector altitude) from radar display
    c. Extract target symbol, track history, altitude, and velocity vector from the radar display
    d. Extract aircraft identification, ground speed, target symbol, primary target or secondary target from full data block
    e. Search the flight progress strip in the flight strip bay
    f. Extract flight identification, aircraft type, and requested altitude from the flight progress strips
    g. Extract route information, previous posted fix, posted fix, and next posted fix from the flight progress strip
    h. Extract time over previous posted fix, calculated time of arrival over posted fix, and remarks from the flight progress strip
    i. Extract route information (i.e., destination), estimated ground speed, and true airspeed from the flight progress strip
    j. Synthesize time, location, route, known pilot intentions and altitude information on aircraft into a mental picture of aircraft path
    k. Project future location and altitude of aircraft with regard to proximity to other aircraft, obstructions, special use airspace, and weather

3. Request range, bearing and/or time message with options
    a. Initiate fix/time readout message for information that may assist the assessment of a possible conflict
    b. Execute fix/time readout message
    c. Extract fix/time readout from the requested message on the computer readout device (results of fix/time readout message
    d. Initiate range/bearing readout message
    e. Execute range/bearing readout message
    f. Extract range/bearing readout message
    g. Initiate range/bearing/fix readout message
    h. Execute range/bearing/fix readout message
    i. Initiate request for route readout (for aircraft of concern)
    j. Execute request for route readout
    k. Detect route of flight readout
    l. Extract range/bearing/fix readout message

4. Force/quick look full data block(s) to examine track information on aircraft
    a. Initiate quick look message (to force radar data from adjacent airspace to radar display)
    b. Execute quick look message
    c. Extract forced radar data from full data block on radar display (results of quick look message)
    d. Initiate display to force data block message (to force full data block from adjacent airspace onto plan view display)
    e. Execute display of forced data block message
    f. Extract information from forced full data block on radar display (results of force data block message)

5. Determine whether aircraft may become separated by less than prescribed minima
    a. Evaluate current and projected mental traffic picture to determine potential situations of less than standard separation

II) Resolve Aircraft Conflicts

A. Perform aircraft conflict resolution

1. Review the potential conflict situation for resolution
    a. Acquire target symbol, full data block, limited data block, conflict data block, and aircraft identification on radar display regarding potential conflict
    b. Extract route display from radar display
    c. Extract altitude and ground speed from full data block of aircraft involved on radar display
    d. Synthesize location, track history, speed, direction, and altitude from limited data block (position symbol and target symbol)
    e. Extract route information, aircraft type, and remarks from flight strips
    f. Extract precipitation from radar display (when weather may be a factor to consider)
    g. Initiate range/bearing readout, range/bearing/fix readout or fix/time readout message
    h. Execute range/bearing readout, range/bearing/fix readout or fix/time readout message
    i. Extract range/bearing readout, range/bearing/fix readout or fix/time readout on computer readout device
    j. Integrate the traffic picture with altitude and speed information into a complete mental traffic picture with regard to the separation of two aircraft potentially in conflict
    k. Evaluate the need to resolve the aircraft conflict.

2. Determine appropriate action to resolve aircraft conflict situation

a. Extract aircraft routes, altitudes, and speeds from the flight progress strip, route of flight display, conflicts alert list, full data block or conflict data block
b. Extract aircraft identification to determine priority handling from full data block
c. Extract aircraft type from the flight progress strip
d. Decide upon action needed to resolve aircraft conflict considering mental traffic picture, weather, aircraft performance, special conditions and viable resolutions options

3. Formulate advisory content
   a. Synthesize a traffic picture, weather information, altitude, route of flight, geographic map data, and an overall picture of the unsafe condition
   b. Decide to issue advisory service based on the information available
   c. Formulate contents of advisory service

4. Issue a traffic advisory in regard to traffic proximity
   a. Transmit to pilot

5. Detect aircraft maneuver in response to advisory
   a. Search full data block, limited data block, and track history on radar display for information pertaining to aircraft maneuvering in response to advisory
   b. Detect changes in lateral movement of the target symbol, track history, and full data block on radar display
   c. Detect a change in altitude and altitude qualifier in full data block
   d. Compare movement change to contents of advisory

5.1.2 Flow/flow-rate conformance

III) Manage air traffic sequences

A. Respond to traffic management constraints/flow conflicts

1. Evaluate traffic management constraints for effect on traffic flow
   a. Acquire target symbol, data block, and geographic map data on radar display for information pertaining to traffic management restrictions
   b. Extract aircraft identification, ground speed, altitude, and altitude qualifier from full data block
   c. Search flight progress strip flight strip bay for information pertaining to a potential violation of flow restrictions
   d. Extract flight identification, aircraft type, computer identification, and strip marking (clearance limit/holding instructions) from flight progress strip
   e. Extract assigned altitude or requested altitude from flight progress strip
   f. Extract route information, posted fix, next posted fix, and remarks from flight progress strip

g. Extract route information (destination, departure point), true airspeed, and estimated ground speed from the flight progress strip
h. Extract calculated time of arrival over previous fix and calculated time of arrival over posted fix from the flight progress strip
i. Search traffic management record for traffic management constraints
j. Extract traffic management constraints (speed, altitude, spacing, etc.) from traffic management record
k. Search sector metering list on inbound list for metering information
l. Extract fix and metering constraints from sector metering list on inbound list
m. Synthesize mental traffic picture, route, altitude, speed, and traffic management into a complete mental traffic picture with regard to the impact of the restrictions
n. Evaluate traffic management and metering information for the effect on traffic flow

2. Review options to bring aircraft into conformance with traffic management restrictions
   a. Acquire target symbol, data block, and geographic map data on radar display to reestablish aircraft within traffic management conformance
   b. Extract aircraft identification (to determine priority handling and conformance requirement) from full data block
   c. Extract altitude and altitude qualifier from full data block
   d. Search flight progress strip flight strip bay for information pertaining to help decide how to bring individual aircraft into conformance with flow parameters
   e. Extract assigned altitude from appropriate flight progress strip
   f. Extract route information, expect further clearance time, and remarks from appropriate flight progress strip
   g. Synthesize extracted information with a mental traffic flow picture in order to decide the appropriate action to bring the aircraft into conformance with flow parameters
   h. Evaluate the appropriateness of vectoring/rerouting to bring aircraft into conformance with flow parameters
   i. Evaluate the appropriateness of changing altitude to bring aircraft into conformance with flow parameters
   j. Evaluate the appropriateness of changing speed to bring aircraft into conformance with flow parameters
   k. Evaluate the appropriateness of holding aircraft to bring aircraft into conformance with flow parameters

3. Choose option to bring aircraft into conformance with traffic management restrictions
   a. Decide to vector/reroute aircraft to bring aircraft into conformance with flow parameters

b. Decide to change altitude of aircraft to bring aircraft into conformance with flow parameters
c. Decide to change speed of aircraft to bring aircraft into conformance with flow parameters
d. Decide to hold aircraft to bring aircraft into conformance with flow parameters

4. Negotiate traffic management action with pilot
   a. Transmit to pilot (options #3 from above)

The significance of the Job Task Taxonomy for this research was 1) to familiarize the author with en route controller tasks and procedures in order to have the background necessary for interviewing small groups of controllers from the Denver Center about current and future roles, responsibilities, and procedures, 2) to use as a reference during the assessment of the candidate controller roles and responsibilities necessary to achieve a trajectory orientation (see Section 7), and 3) to illustrate the tactical nature of today's procedures. In particular, with respect to the third item, the Job Task Taxonomy indicates that tasks for CDR and flow-rate conformance are two separate, de-coupled tasks. A key feature of trajectory orientation is the coupling of these two tasks. Although controllers may in fact couple these two tasks at times, the lack of DST technology makes it difficult to perform these functions efficiently.

The tactical nature of today's procedures is further exemplified by field test evaluations at Ft. Worth Center (reference 17) using a DST for trial planning in transition airspace. The trial planning capability allowed test controllers working in shadow mode to plan direct-route resolutions for Ft. Worth Center arrivals, departures and overflights. The direct-route resolution is strategic in nature – it is conflict-free beyond the time horizon of a controller unsupported by DST technology. In addition, direct routes generally offer a flying time savings to the airline. The advantage that the trial planning tool offered to controllers was significant for direct-route resolutions. Without trial planning capability, controllers were using direct-route clearances only 19% of the time. With trial planning, the test controllers chose direct-route resolutions 33% of the time. They also used trial planning to check direct routes to downstream fixes for departing aircraft. This field test is indicative of the strategic planning controllers would continue to choose to do (but not required to do) if given the DST capability. On the other hand, the trial planning capability coupled with the today's flow-rate conformance procedures (at the sector) clearly demonstrated the tactical nature of those procedures and the negative impact those procedures had on the control of arrival traffic into high-density terminal areas. The lack of metering intent for the conflict probing of arrival traffic resulted in trajectory-inefficient and workload-intensive actions by the controllers. (One solution to this problem is to have automated resolutions for flow-rate conformance that include intent information. This will be discussed in more detail in Section 5.3)

5.2 Strategic planning in today's operations

The traditional roles and responsibilities of the D-side position are to monitor and coordinate incoming flights via flight strips to predict and adequately manage aircraft conflicts (e.g., by handing-off early, by denying a handoff, or by communicating with the R-side to prepare him/her for upcoming conflicts.). In contrast, interviews with controllers from both Cleveland and Denver Centers indicate that the D-side rarely performs these roles in today's environment. In fact, they used the term "old-school" to describe these roles. Controllers at the Denver Center indicated that the primary role of the D-side is management of paper flight strips. During rushes, the large task time associated with the collective management of paper flight strips does not afford the D-side with the opportunity to look into upstream sectors to determine the quantity and complexity of the traffic flowing into his/her sector. (As discussed in Section 7.1, D-side controllers from Memphis and Indianapolis Centers are using these traditional roles today because of the strategic detection, trial planning, and electronic flight data capabilities provided by URET.) Thus, as an example, the D-side is not able to assess the appropriate conditions for receiving a handoff or whether a handoff should be denied. Controllers at Cleveland Center concurred with this perspective and also added that during a "rush", the D-side assists the R-side with pilot read-back of clearance information. During a rush, communication with several aircraft in rapid succession is often needed – and the D-side assistance with the read-back ensures that the aircraft understands the clearance, mitigating the incurred workload that occurs when a pilot executes the wrong clearance. (Because the D-side is assisting the R-side in this manner, it is often the case that the "by the book" marking of paper flight strips is delayed until the rush is over.)

Even if not all D-side controllers perform their historic roles, there is significant coordination between sectors and the traffic management unit (TMU) that provides some level of strategic planning to the sector. However, before that is discussed, a brief description of the function of the TMU should be mentioned. The TMU has access to tools that allow for a much larger perspective of the traffic flow through sectors within a Center as well as traffic entering the Center from adjacent Centers. This enables the TMU to predict sector congestion long enough in advance (typically an hour or more) so that “flow” solutions can be derived and implemented by the specialist position within the TMU. The goal of these solutions is to ensure that sector capacity is not exceeded while maximizing efficiency. The most common solutions are to re-route traffic and/or impose flow-rate conformance constraints. Another solution is to require ground holds at airports for departing aircraft for a specified duration of time. (It is worth mentioning here that a Center cannot require ground holds at airports in another Center's jurisdiction. This would require coordination between the impacted Center, the Air Traffic Control System Command Center, and the Center where the ground holds should be imposed.)

When the strategic planning horizon within a Center's airspace is much less than an hour (e.g., 15 minutes), another position within the TMU, the traffic management coordinator (TMC), becomes active in traffic management. TMCs are typically assigned to monitor the busiest streams of traffic within a Center (e.g., in Cleveland Center there is a TMC that focuses on O'Hare-bound traffic originating from the East Coast). The TMC has the responsibility of maintaining the efficiency of those streams by determining plans to fill gaps and merge streams. He/she coordinates these plans with the area supervisor (i.e., the supervisor of a group sectors within a Center) who in turn coordinates with the controllers of the impacted sectors. As an example, for a merging problem between two streams of traffic subject to miles-in-trail restrictions, the TMC would coordinate with the supervisor of the sectors upstream of the merge point to maneuver aircraft. The goal is to have an efficient and seamless merging of traffic so that the sector that contains the merge points does not become overloaded. The supervisor then coordinates with the upstream R-side, who determines a delay maneuver and issues the clearance. The TMC, in a certain sense, is performing the historical D-side role (i.e., looking upstream) with the difference being that the TMC cannot communicate directly with the R-side controller.

5.3 Current procedures and techniques that inhibit a trajectory orientation

Each sub-section listed below identifies procedures or techniques that could inhibit a trajectory orientation. Each sub-section title is followed by a brief description of the current-day operations problem that is solved or alleviated by utilizing the technique or procedure identified. This is followed by a more thorough explanation of the rationale behind the procedure or technique. Finally, new solutions are offered that both address the current problem and achieve a trajectory orientation. The new solutions may require new technology (e.g., decision support tools, communication, or surveillance) and/or procedures. Procedures/techniques considered exceptional in nature (e.g., radar display failure resulting in non-radar procedures to maintain safe separation) are outside the scope of this assessment.

5.3.1 Preferred routes and the NRP

This procedure addresses the problems of managing air traffic in congested airspace.

ATC “preferred routes” refer to a set of high and low altitude routes published by the FAA primarily for the congested airspace of the East and Midwest. Aircraft are required to use these routes when flying between major airports. The exception to this is those aircraft that qualify for the National Route Program (NRP). From an ATC perspective, the advantage to preferred routes is that air traffic is predictable. For example, controllers learn to anticipate certain types of problems during rush periods. In addition, sector boundaries can be partitioned so that route intersections are located near the center of the sector (reference 13). Route intersections often have a higher probability of aircraft conflict. By placing the intersection near the center of the sector, the controller has ample time to resolve it. The disadvantage to preferred routes is that they do not permit the users to choose more optimal routes, either with respect to wind direction or route directness. This has a significant effect on fuel efficiency and flight time savings.

The FAA initiated the NRP to address the fuel and flight time concerns of the user community. NRP allows aircraft with level cruise flight above FL290 to request more optimal routes. ATC preferred routes must still be used within 200 nm of the departure and arrival airport. In today’s operations, aircraft utilizing the NRP often cause problems for controllers because controllers do not have adequate DST support to readily determine if NRP aircraft are conflicting with aircraft on established airways. As one controller from the Cleveland Center stated, “I can have twenty aircraft in my sector with one NRP aircraft causing all the problems.” However, in future operations utilizing trajectory orientation and EDA-like DST technology, NRP is a large step in the right direction. DST technology with integrated CDR and flow-rate conformance would enable controllers to effectively handle more optimal routing while dynamically throttling the flow as needed to address dynamic capacity overloads (with minimum deviation from user-preferred routing). The 4D trajectory predictor algorithms residing in EDA are not constrained to established routes. In addition, these capabilities would most likely permit a reduction in the 200 nm arrival/departure restriction giving the user more flexibility to choose optimal routing.

5.3.2 Radio communication

In today’s operations, radio is the primary means of controller-pilot communication. Radio communication enables controllers to issue clearances, request information about aircraft position, notify pilots of weather or turbulence, inform pilots of radio frequency changes, deliver holding instructions, etc.

Two-way radio communication during rush periods often utilizes a controller’s auditory and cognitive resources to the point that other tasks (e.g., planning tasks) become lower priorities. Controllers at the Cleveland Center estimated that during peak rushes that lasted approximately 30 minutes, they were using radio resources 80-90% of the time over that period. Many of the controller-pilot exchanges are routine and repetitive (e.g., during handoff, informing the pilot of the next sector's frequency). Cleveland Center controllers noted that a primary function of the D-side position during rushes is to assist the R-side with the confirmation of the pilot readback of clearances.

Reducing communication workload would result in more opportunities for controllers to perform trajectory-oriented planning. The solution that appears to have the most promise is controller-pilot data link communication (CPDLC). It is expected that CPDLC will drastically reduce the workload associated with handoffs and transfer of communication because these messages can be automated. CPDLC would not require the D-side's assistance in the pilot readback of clearances. Combining CPDLC and DST technology so that DST resolutions can be sent directly as data linked clearances with the click of the trackball is another potential candidate for reducing communication workload.

5.3.3 Reducing sector size

This technique addresses the problem of managing controller workload in a sector that consistently sees high levels of traffic.

Currently, sectors are partitioned both vertically and horizontally in a logical manner based on traffic flow and the structure of airways (reference 14). Because of the huge increase in domestic air travel since airline deregulation, traffic count in individual sectors has become unmanageable in certain sectors, particularly in the Northeast corridor. One solution has been to reduce the volume of the sector airspace (either vertically or horizontally) and thus reduce the average number of aircraft in the sector. With fewer aircraft, the controller has reduced communication workload and fewer tracks on the display that require his/her vigilance. This approach works well as long as the aircraft are in the sector for a long enough period of time that allows for adequate controller planning (e.g., CDR, handoff requirements, flow rate conformance).

Some sectors have been reduced in size to the point that any further reduction would be counter-productive. With respect to the total aircraft time in the sector, the controller spends more time transferring and receiving handoffs. Also, the small sectors do not allow the controller to develop a mental "big picture" of the air traffic needed for adequate planning. The small sectors discourage strategic planning because the planning would require coordination with other sectors, adding to controller workload. In this situation, new methods must be utilized to account for the anticipated growth in air traffic. CPDLC is one solution that has already been discussed. Another solution is DST technology that can assist the controller with conflict detection and resolution. However, if the controller also must merge/sequence/meter arrival traffic or feed such an adjacent sector, the resolution must account for downstream flow rate conformance, in addition to CDR, to be fully effective. Otherwise, resolution actions will only be temporary fixes that will require further controller action in the next downstream sector. DST technology coupled with trajectory-oriented inter-sector planning would alleviate separation, merging/spacing, and metering problems in busy downstream sectors. This concept will be discussed in greater detail in Section 7.

5.3.4 Monitor Alert and the Enhanced Traffic Management System

The Enhanced Traffic Management System (ETMS) assists with traffic management and strategic control of traffic flow at three levels: 1) The Air Traffic Control System Command Center, 2) The twenty en route Centers, and 3) TRACON facilities. ETMS performs flight data collection from an integrated network of computers and communications systems to display current and projected air traffic for the entire national airspace via the traffic situation display. The traffic situation display and supporting software provide the TM personnel with a tool for highlighting specific regions of airspace (and the corresponding current or projected traffic) or selecting specific aircraft tracks or groups of tracks (e.g., all traffic bound for Chicago O'Hare). They use this information to forecast congestion and delays and determine actions to minimize them.

Average Sector Flight Time	MAP VALUE
3 min	5
4 min	7
5 min	8
6 min	10
7 min	12
8 min	13
9 min	15
10 min	17
11 min	18
12 min or greater	18

Table 1. Monitor Alert Parameter for Average Sector Flight Times

Monitor alert uses ETMS data to compare the projected aircraft count in a sector with the Monitor Alert Parameter (MAP) value listed in Table 1 from the FAA 7210.3P. If the aircraft count exceeds the MAP value, an alert is sent to the traffic manager along with the traffic demand projection. TM specialists then determine the least restrictive actions to ensure that demand does not exceed sector capacity.

The time horizon (look ahead) for the monitor alert function is required to be at least one hour, but 1.5 to 2.5 hours is recommended. Predictions are in 15 minute increments. The alerts are displayed as red (active alert) or yellow (projected alert).

Traffic management personnel from the Cleveland Center stated that in some situations, alerts were given only fifteen minute prior to the sector becoming "red". With such short notice, little can be done to divert traffic from the red sector without significant re-routing and delays. During these periods of high sector loading, the controller must manage his workload by focusing only on separation and communication. Strategic planning would no longer be feasible and, based on Denver Center controller interviews, the requirement to meet crossing restrictions is often temporarily dropped until the traffic decreases to more manageable levels. The next downstream sector then has additional workload because the traffic has not met expected requirements. In addition, it is sometimes the case that red sectors traverse from sector to sector in an eastward or westward direction across an entire Center's airspace. This results in reactive, rather than proactive, controller actions and clearly inhibits a trajectory orientation.

This issue highlights an important point with respect to trajectory orientation. Just as trajectory orientation necessitates that adjacent controllers depend on each other for well-planned flow, so to it depends on accurate regional/national-level traffic management to provide sector loading at a manageable level. There are currently several efforts to improve traffic management, through upgrades to ETMS as well as development of new traffic management tools. In addition, estimating the complexity of traffic in a sector rather than just aircraft count will be a more useful measure for determining sector capacity.

5.3.5 Human Error

Despite all the technological advances, NAS will always be a system managed and utilized by human operators. As such, mistakes will be made that will challenge trajectory-oriented strategic planning efforts and cause short-term inefficiencies in the system. The few examples mentioned here were identified during controller interviews/visits, but the list is by no means exhaustive. In fact, the author considered these examples to be nearly outside the scope of the assessment, but decided that they should be documented so that as more detailed requirements for procedures and DST capability are derived, there can be an effort to mitigate the consequences of human errors to the extent possible.

1. During peak periods, Cleveland departures bound for Chicago O'Hare are often held on the ground for 45 minutes due to airways filled to capacity with O'Hare-bound traffic from the East coast. (This condition is often referred to as "aluminum overcast.") Cleveland tower must request a departure clearance from the traffic management unit (TMU) of Cleveland Center to ensure a slot is available when the aircraft enters en route airspace. If a miscommunication occurs, the result could be an aircraft departs prematurely. Once the aircraft has departed, controllers and TMC do their best to effectively squeeze the aircraft into the stream of traffic. This would potentially require the tactical maneuvering of several aircraft and most likely distract the controller for several minutes from other planning efforts.
2. Controllers from Cleveland Center indicated that in some instances they have not provided the required spacing between aircraft because they were unaware of dynamic TMU spacing requirements. An obvious solution is to integrate the spacing restrictions from the TMU so that it is automatically shown on the R-side display of the sector affected by the constraint. This method is currently utilized for displaying metering times to sectors at Ft. Worth Center.
3. Ground-air miscommunication can result in the pilot performing the wrong control instruction. Monitoring for compliance is the controller's responsibility, but in planning situations that require quick response times, by the time the controller can correct the pilot's control action, the initial plan may no longer be valid (e.g., a larger vector may now be required to maintain separation).

5.4 Need for accurate strategic planning

One important point from the controller interviews is the fundamental fact that controllers have been trained to act and think tactically, not strategically. Emerging DST capabilities have demonstrated, under limited conditions in the field, the ability to enable more strategic planning by controllers. However, simply making DSTs available to controllers would not necessarily result in strategic planning because the controller's mindset and procedures are still predominantly based on a tactical culture and environment that dates back several decades.

In addition, controllers are reluctant to strategically resolve flow-rate conformance and conflict problems (a fundamental requirement of the trajectory orientation concept). This reluctance is due, in large part, to the general uncertainty and lack of predictability they expect over a strategic time horizon. To clarify these issues further, results from the controller assessment are summarized below. Eight core issues were identified as obstacles that prevent or inhibit controllers from performing effective/accurate strategic planning. These issues are ranked here in terms of their impact on enabling a trajectory orientation:

1. Controllers are not responsible for meeting flow-rate constraints or resolving conflicts of other sectors.
2. Strategic resolutions may be insufficient in resolving conflicts or meeting flow-rate constraints.
3. Inter-sector resolutions may interfere with an adjacent controller's plans.
4. Strategic resolutions may lead to conflicts with other aircraft because of inadequate situation awareness.
5. Strategic resolutions have a lower priority compared to other controller tasks.
6. Conflicts may resolve themselves because they are actually false alarms.
7. Conflicts may resolve themselves because of unpredictable events.
8. Strategic resolutions may lead to conflicts or flow-rate conformance problems with other aircraft because of simultaneous and conflicting actions by adjacent controllers.

The following sections describe these core issues in greater detail and present potential solutions.

5.4.1. Controllers are not responsible for meeting flow-rate constraints or resolving conflicts of other sectors.

(The conflict geometry this issue refers to are the Inter-sector and External Intruder cases in Figure 5 of Section 7.) This was the first issue raised by the controller working groups when the topic of inter-sector planning was discussed. The current ATC system clearly assigns responsibility and control authority to individual sectors. Although there are exceptions, generally speaking, controllers are only responsible for resolving conflicts that occur in their own sectors. Similarly, controllers are responsible for meeting flow-rate constraints at their respective exit boundaries or metering fixes. The advantage to these methods is that one and only one sector can control an aircraft. In the case of an operational error (e.g., violation of the minimum separation rule), the fault is readily determined. The disadvantage is that there is no impetus for controllers to collaborate on trajectory oriented inter-sector planning. Without such inter-sector planning, achieving a trajectory orientation is not possible.

Potential Solutions: Unlike many of the other issues discussed below, the solution for this issue requires changes to many aspects of today's ATC operations. New tools and procedures must evolve that give controllers confidence that trajectory-oriented planning is beneficial to all sectors. Only when all eight issues pertaining to strategic planning are addressed will the right conditions exist for pro-active, widespread participation in trajectory-oriented, inter-sector planning.

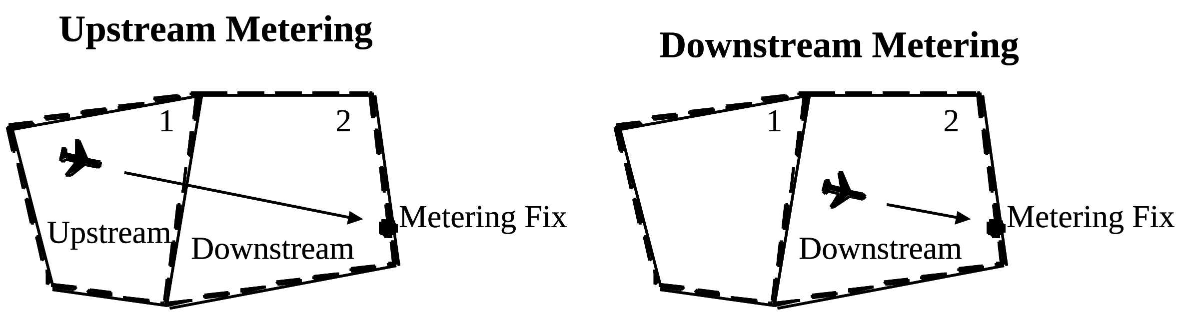

Figure 5. Metering Scenarios

5.4.2. Strategic resolutions may be insufficient in resolving conflicts or meeting flow-rate constraints

The controller using "rule of thumb" calculations that are too gross for the given scenario would most likely cause inadequate strategic resolutions. As an example, controllers often use a simple formula based on the distance to a conflict and the desired lateral separation to determine the required vectoring for an aircraft in conflict. Of course, this rule of thumb does not account for wind, errors in ground speed, or conflict geometry so the controller's experience and skill becomes an important factor in calculating a resolution advisory that is sufficient, but not excessive. (This becomes more difficult for strategic time horizons because position uncertainties tend to grow linearly with time.) In an effort to minimize the deviation to an aircraft's trajectory, a controller may issue a heading change to an aircraft that, over a period of time, proves to be insufficient in separating it from the other aircraft. This artificially increases the controller's workload because now the controller has to recalculate and reissue the advisory. Also, it's often the case in which the pilot, who may surmise about the competency of the controller, wants an explanation for the need of the new advisory (further distracting and detracting the controller from other tasks).

Potential Solutions

A solution for inadequate resolutions is trial planning capability, such as that reside in the User Request Evaluation Tool (URET) (References 15-16) and EDA (References 2-3, 17). For example, a controller could trial plan a 10-degree heading change. If the trial planning algorithm indicates the heading change is sufficient, the controller would issue clearances based on the plan. If the heading change is insufficient, the controller can use the automation to develop a trajectory plan with acceptable separation. More importantly, trial planning combined with longer time horizons afforded by strategic planning provides an excellent opportunity for controllers to use speed control as a viable choice for absorbing delay to meet metering or spacing constraints.

5.4.3. The inter-sector resolution may interfere with an adjacent controller's flow-rate conformance plans.

As an example, if two aircraft in an upstream sector (see External case in Figure 5) will conflict five minutes into the downstream sector, the upstream controller is required to resolve the conflict before the aircraft is handed off. When spacing constraints are required in the downstream sector, the upstream conflict resolution might interfere with the aircraft spacing plans of the downstream controller. He/she would then need to resolve the new problem and issue an additional clearance to the aircraft. One method currently employed by controllers to avoid this situation is to handoff the aircraft early so the downstream controller can resolve both the conflict and the spacing conformance. The drawback to this method is that the controllers are dealing with the traffic tactically rather than strategically, which is particularly inefficient for delay (metering) situations.

Potential Solutions: The solution is for strategic (upstream) planning of resolution maneuvers aided by DST functionality that accounts for integrated downstream flow-rate conformance and separation. The technology must support a common situational awareness across sectors to ensure that plans and actions are complementary.

5.4.4. Strategic resolutions may lead to conflicts with other aircraft because of inadequate situation awareness.

A primary reason that strategic resolutions lead to conflicts with other aircraft is inadequate situation awareness across sectors. The R-side controller maintains situation awareness of the sector he/she has responsibility for primarily by monitoring the sector via the display system. The R-side controller maintains situation awareness of an adjacent sector by reviewing the flight strips and/or consulting with the D-side controller (if the sector is staffed with at least two controllers). Controller situation awareness can be negatively affected by lack of data, high workload, complacency, or lack of vigilance. Regardless of the cause of inadequate situation awareness, or which sector it occurs in, the result is the controller's mental picture of the airspace does not accurately reflect all aircraft. Consequently, the controller may determine a resolution that can lead to conflicts or flow-rate conformance problems with those aircraft.

Potential Solutions: The problem for conflicts due to inadequate situation awareness can be mitigated by DST functionality that provides situational awareness cues on several levels. At one level, such cues may be integrated as part of the trial planning and/or automatic resolution advisories for separation and flow-rate conformance. This would augment a controller's situational awareness by alerting the controller to cases where resolution plans cause other problems. At a more basic level, situational awareness can be enhanced by DST cues that call a controller's attention to situations requiring greater scrutiny (e.g., a flight that is not correlated with it's predicted path).

5.4.5. Strategic resolutions have a lower priority compared to other controller tasks.

The FAA controller handbook, referred to as 7110.65 (Reference 11), states:

> "Give first priority to separating aircraft and issuing safety alerts as required in this order. Good judgment shall be used in prioritizing all other provisions of this order based on requirements of the situation at hand."

No controller interviewed for this study considered separating aircraft, based on a conflict detection time horizon of 15 to 20 minutes, a "first priority." Obviously, controllers would deal with tactical conflicts before the strategic conflicts/flow-rate conformance problems because the safety of the aircraft is more imminent. In the event that there are no tactical conflicts, the controller in most situations would be inclined to perform low priority tasks, such as housekeeping, over strategic resolution. As one controller stated, "twenty minutes is an eternity to a controller," but twenty minutes is also the preferred time horizon for efficient flow-rate conformance. Ironically, the lack of strategic planning today results in a higher tactical workload that, in turn, reduces the opportunity to perform strategic planning.

Potential Solutions: The solution requires a fundamental change to the environment that controllers have been trained to support. It also implies a shift in controller roles and responsibilities. The circumstances presented to controllers in any given situation must have adequate solutions, via new tools and procedures, to give them confidence that by acting and thinking strategically, they are improving the overall traffic flow and are not increasing their workload.

5.4.6. Conflicts may resolve themselves because they are actually false alarms.

Prediction errors occur because of uncertainty in actual ground speed, altitude rate, and radar track when a controller projects each aircraft's trajectory. The controller may falsely predict a conflict situation that, if left alone, would have resolved itself.

Potential Solutions: The solution for prediction errors and the resulting false alarms is through automated 4D trajectory predictor algorithms, such as those residing in URET and EDA. These algorithms have been studied for several years and are well-suited for addressing this particular problem. Effectiveness can be improved by including functionality to accurately reflect or model the intentions of the pilot and/or adjacent controllers.

5.4.7. Conflicts may resolve themselves because of unpredictable events.

The longer the conflict detection time horizon, the higher the probability that something unpredictable or unintended will occur that results in the conflict resolving itself. For example, the pilot of one of the conflicting aircraft may request an altitude and/or speed change (e.g., due to turbulence) or a heading change (e.g., due to a weather cell in its path) prior to the conflict becoming tactical (i.e., within the time horizon of today’s radar controller). In these cases, granting the pilot request resolves the conflict.

Potential Solutions: Since this issue pertains primarily to separation conflicts, rather than flow-rate conformance problems, one solution is for the controllers to delay a conflict resolution until the probability is high for the conflict to occur. This is discussed in more detail in the section on Tactical Detection vs. Strategic Detection of Conflicts and Flow-rate Conformance Problems.

5.4.8. Strategic resolutions may lead to conflicts or flow-rate conformance problems with other aircraft because of simultaneous and conflicting actions by adjacent controllers.

This case is rare, but was the cause for a near-miss between two aircraft at the Denver Center. Simultaneous trajectory changes to aircraft in two separate, but adjacent, sectors can lead to what otherwise would have been a preventable conflict. In this case, the controller has adequate knowledge of aircraft in adjacent sectors to determine a strategy to resolve a conflict in his sector that would not interfere with aircraft in the adjacent sectors. However, the controller does not know the actions being performed simultaneously by a controller in an adjacent sector unless one of the controllers takes the initiative to coordinate with the other. The simultaneous actions have the potential to negate the intended effect, resulting in another conflict or flow-rate conformance problem. Following normal sector-to-sector communication procedures would prevent this case from occurring, but the fact that it does occur is a cause for concern.

Potential Solutions: Although a rare problem, the solution for conflicts and flow-rate conformance problems due to simultaneous actions in today's operations is to emphasize correct procedures related to sector-to-sector communication.

In a future DST environment that supports trial planning and automatic resolution, this problem can and must be avoided because controller trust in the DST is at stake. As one controller stated, "Trust is hard to gain, but easy to lose." The option that appears to be most favorable is "cross-referencing." Cross-referencing tests any newly created trial plan, whether controller-derived or computer-derived, against all active flight plans as well as all pending trial plans that correspond to other sectors. If the newly created trial plan conflicts with any of the other plans, then the controller is notified of the discrepancy and must decide on a new course of action.

5.5 AERA

This section, as required by the SOW, provides a summary of the Automated En Route ATC (AERA) program as it applies to the objectives of this research. The purpose to leverage lessons learned from AERA to mitigate the risk associated with EDA development.

AERA was intended to be implemented in three stages (reference 18). AERA 1 consisted of conflict detection and trial planning functionality and essentially represents today's implementation of URET (see Section 7.1 for a brief operational description of URET). AERA 2 added automated problem resolution and automated aids for controller coordination to the AERA 1 baseline (currently proposed for implementation within Free Flight Phase 2 as PARR). The AERA 3 concept incorporated a high level of automated decision making, (i.e., some clearances were envisioned to be issued to the aircraft without controller involvement). Since AERA 2 most closely resembles EDA functionality, the remainder of this section will focus on the AERA 2 findings that pertain specifically to this research.

The AERA 2 (references 19-22) concept minimizes coordination between controllers for inter-sector conflicts by only notifying one controller of the conflict. When a conflict is detected, an automated problem resolution algorithm looks at possible resolutions for both aircraft. The different resolutions are ranked according to how each aircraft would be penalized if the resolution was implemented. There could potentially be several resolutions for each aircraft that adequately resolve the conflict, but only one resolution can be ranked highest. The sector that "owns" the aircraft with the highest resolution ranking is notified of the conflict. The controller can either accept or reject the automated resolution. If the controller rejects the resolution, he/she can trial plan another solution or notify the controller who "owns" the other aircraft to determine a resolution. As will be discussed in section 7, minimizing coordination between controllers is a desirable feature of a DST. The candidate concepts described in Sections 5.3, 5.4 and 5.8 would most likely benefit from an algorithm similar to the one described here.

The strategic upstream nature of AERA 2 (Reference 23 and discussion with key AERA researchers) was predicted to significantly reduce tactical resolutions of problems, although it was expected that tactical control would still be required near major airports. In addition, AERA 2 strategic planning was expected to increase controller productivity and use of airspace. The AERA 2 concept required the controller to always maintain a model of intent of the pilot in the automation system. Sector and Center boundaries were expected to be largely transparent to the automation. Finally, AERA 2 would determine the resolutions to comply with traffic management metering constraints while maintaining separation.

Although the AERA 2 operational concept compares closely with EDA and the trajectory orientation concept, there are two differences worth noting. First, the AERA 2 requirement for time of arrival for metering was plus/minus one minute whereas EDA was approximately 10 seconds. For arrival streams in the terminal area, meeting AERA 2 metering requirement would not guarantee safe separation, although it would certainly be sufficient for maintaining sector capacity constraints. EDA metering requirements, on the other hand, could be used to ensure safe separation. Second, EDA utilizes the same approach as used by flight management system (FMS) algorithms. One feature of FMS is to maximizes the use of the speed envelope for maintaining required times of arrivals. This allows a greater use of speed control over the approach used by AERA 2.

6 Discussion

6.1 Tactical Detection vs. Strategic Detection of Conflicts and Flow-rate Conformance Problems.

Early in this research, the assumption was made that strategic detection (15 – 20 minute time horizon) of conflicts and flow-rate conformance problems would generally result in the most optimal/efficient resolutions. However, analysis of strategic planning issues in Section 5.4 indicated that controllers' concern regarding the operational utility of strategic planning was based on the relative trajectory uncertainty in today's air traffic operations. Further investigation revealed that the majority of their concerns were related to strategic detection and resolution of conflicts (specifically as presented in 5.4.5-5.4.7 above) rather than the strategic detection and resolution of flow-rate conformance problems. Two points are discussed below that suggest a trajectory orientation is still achievable despite a strategy that permits tactical detection of conflicts.

The first point is that, even with accurate DSTs, wind uncertainties over a 20-minute time horizon can still result in detection errors along the flight path that are significantly large relative to the 5 nm separation criteria (Reference 24). Depending on the conflict geometry, this can result in false alarms or missed alerts that needlessly distract the controller. However, those same detection errors are much smaller relative to typical traffic management spacing requirements of 10-40 nm. Consider the case where two merging aircraft are currently predicted to be spaced 5 nm apart but the requirement is for 20 nm spacing. Even with an uncertainty of +/-3 nm in a DST advisory, the upstream controller can nominally plan to absorb all the delay leaving the downstream controller with the responsibility for correcting any unacceptable deviations that develop. With the nominal conformance plan, the downstream controller only needs to intervene by exception, rather than by the rule. When required, such exceptional actions would only require fine-tuning compared to the original delay-absorption plan.

The second point is that waiting to resolve a separation conflict tactically is not nearly as inefficient as waiting to resolve a flow-rate conformance problem tactically. The maximum amount an aircraft needs to be maneuvered to resolve a conflict would be slightly greater than the separation criteria (e.g., 5 nm in radar-controlled en route airspace). In comparison, delays for flow-rate restrictions (e.g., arrival metering) can typically exceed 4 min (approximately equivalent to 20-30 nm of flight). A longer time horizon is required for efficient flow-rate conformance than for conflict resolution.

The purpose of mentioning these two points is to suggest that a trajectory orientation could still be achieved by detecting conflicts on a tactical time horizon rather than a strategic horizon. In contrast, detecting flow-rate conformance problems on a tactical time horizon would clearly inhibit a trajectory orientation – strategic detection is mandatory. Lastly, tactical detection of conflicts would reduce the number of false alarms and missed alerts because the reduced time horizon limits the growth of trajectory-prediction uncertainties such as wind and pilot/controller intent.

One final point concerning tactical vs. strategic detection of conflicts needs to be clarified. When considering time horizons, it is important to distinguish between problem detection and problem resolution. Regardless of whether a conflict is detected/alerted on a tactical or strategic time horizon, if it involves a flow-restricted flight, the resolution should be strategic in nature (i.e., in conformance with flow-rate restriction and nominally conflict-free to the meter fix). The point is that if it is necessary to re-plan a flight to resolve a problem, automation-assisted resolutions should help the controller avoid new problems in the foreseeable future (i.e., the DST time horizon). For example, if a flight must be re-planned for a metering delay, the re-plan should be nominally conflict-free to the meter fix. Alternatively, if a metered flight falls into conflict while in conformance, the conflict-resolution action should be nominally in conformance with the metering restriction. In summary, if the controller must throw a stone, they might as well use the decision support technology to aim the stone to hit two birds. This hybrid concept allows the best aspects related to problem detection and resolution to be combined.

7 Evaluation of Candidate Controller Roles, Responsibilities, and Procedures

One of the primary goals of this research is to evaluate various operational concepts under consideration in the USA and Europe. The goal of this section is to identify advantages and disadvantages of roles, responsibilities and procedures associated with operational concepts specifically outlined in the RTO-34 SOW. In addition, another candidate concept, the strategic "upstream team" concept, based on suggestions from the controller working groups is also discussed.

All the candidate concepts, with the exception of the concepts using a Multi-Sector Planner (MSP) position (i.e., Candidate 5 & 6), assume that electronic flight strips or some other replacement to paper flight strips is available. This is based on overwhelming opinion from the controller interviews that the current D-side task of managing paper strips during peak periods does not allow time to perform tasks related to strategic planning (at the time when strategic planning is most critical). The controllers that had some experience with electronic flight data lists via URET spoke highly of the concept. Although this is not a replacement for paper flight strips, it appears to be a step in that direction. (The issue of flight strips is inconsequential for MSP-like Candidates 5 & 6 because these candidates are independent of R-side/D-side workstation equipment and tasks.)

Other assumptions for the candidate concepts:

- The position responsible for the strategic planning is also responsible for meeting the requirements (e.g., altitude/crossing restrictions) specified in intra-Center standard operating procedures (SOP) and/or inter-Center letters of agreement (LOA)
- The D-side position in the sector responsible for strategic planning for a given candidate concept is also responsible for maintaining the DST model of intent when a clearance is issued

A general assumption is made that the sector is busy enough to require exactly two controller positions. In reality, the sector may have only an R-side position, in which case he/she assumes the D-side responsibilities as well. For the instances where a third controller is needed for the sector, the specific responsibilities will not be addressed because the responsibility of this position is to assist the R-side and D-side in whatever way is most appropriate. This varies based on the particular sector and the style and preferences of the individual R-side and D-side controllers.

As mentioned in the previous section, strategic solutions of flow-rate conformance problems is more critical to achieving a trajectory orientation than strategic resolutions of conflicts. Priorities for controller actions for all candidate concepts are listed below. These priorities ensure safety and maximize trajectory-oriented planning:

1. Tactical conflict resolution
2. Strategic flow-rate conformance

3. Strategic conflict resolution

The candidate concepts are assessed in a systematic manner by their ability to efficiently manage different types of metering, conflicts and/or spacing problems. Metering conformance problems are depicted in Figure 5.

For conflicts and/or spacing problems, the different types were decomposed into four categories, depicted in Figure 6, by previous NASA researches (reference 25) and encompass the most widely occurring problem scenarios. The naming convention (e.g., External Intruder, etc.) created by those researchers has been used again here for consistency. The terms 'upstream' and 'downstream' are used throughout this section. Downstream refers to the sector where the conflict (i.e., loss in required separation) actually will occur if no corrective action is taken. It also refers to the sector where there will be a violation of a spacing constraint at the boundary if no corrective action is taken. Upstream refers to the sector where the aircraft geographically reside during the time period that the conflict and/or spacing problem is being detected and/or resolved.

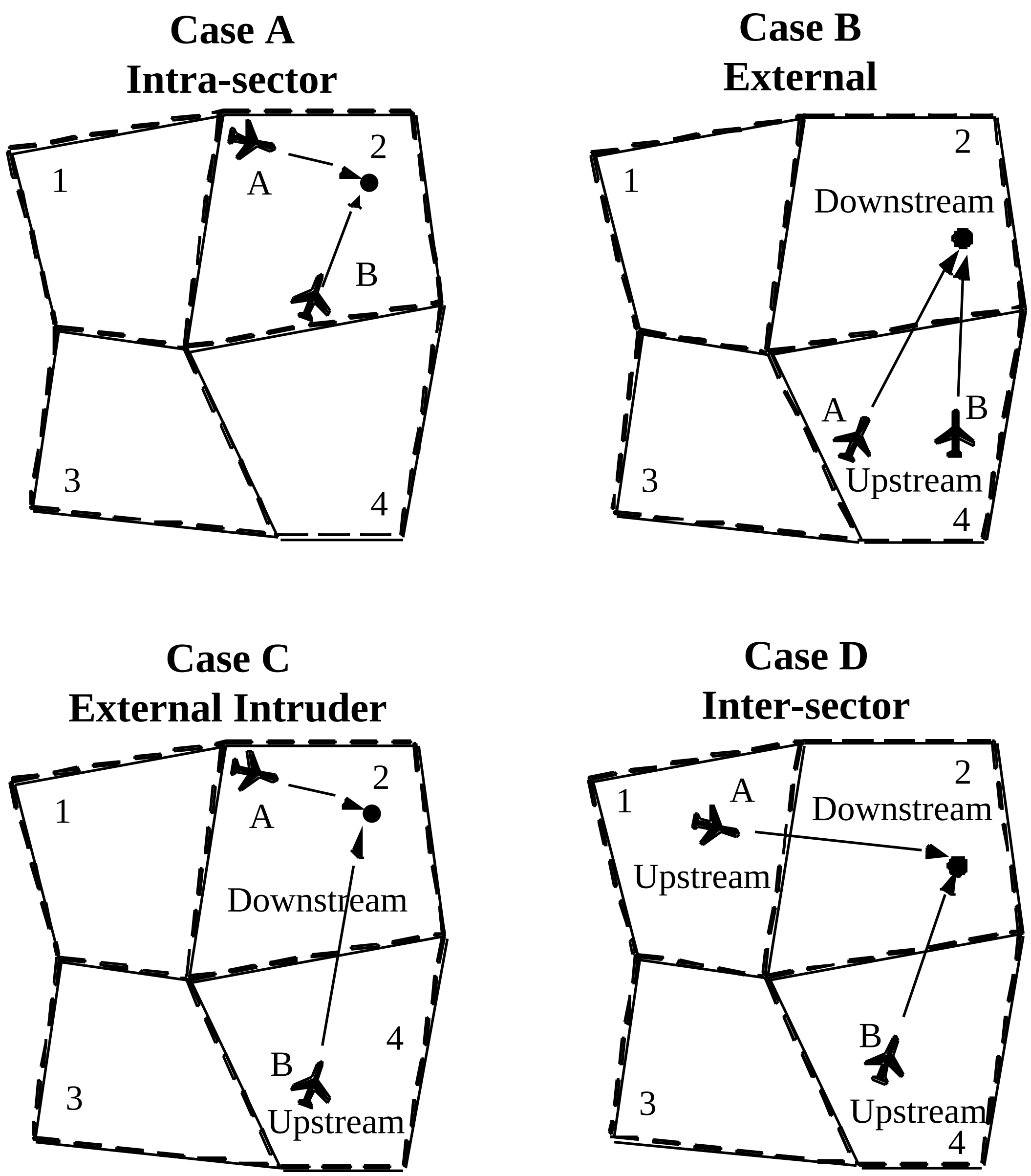

Figure 6. Conflict and Spacing Constraint Scenarios

7.1 Candidate 1 URET-like procedures

This concept was inspired by Free Flight Phase 1 URET procedures (References 13,15-16) and current-day responsibilities with EDA-like DST capabilities. To achieve a trajectory orientation, the downstream D-side uses a DST for strategic conflict detection and flow-rate conformance. The DST is configured to notify only the D-side position in the sector where the spacing violation and/or conflict is predicted to occur. In the case of metering, the DST notifies the D-side of the sector that contains the metering fix. The D-side determines the sector(s) in which each problem aircraft is located and the time and/or distance before the aircraft reach the downstream sector boundary.

For spacing problems or conflicts, the downstream D-side controller has two options that depend on the location of the aircraft and the time to the sector boundary. The first option is to utilize the DST to determine a solution for the spacing problem and/or conflict. (The solution can result from either trail planning or automated resolutions.) The downstream D-side then cues the upstream D-side controller(s) who confers with his/her R-side partners to agree on a resolution strategy for one or both aircraft. Upon agreement, the upstream R-side(s) issues the clearance to the aircraft. In the Inter-sector case (case D of Figure 3), the D-side would potentially need to coordinate with upstream controllers in sectors 1 & 4. In the External case, (case B of Figure 3), the D-side would need to coordinate only with sector 4. In the External Intruder case, the D-side would need to coordinate with his/her R-side as well as sector 4. After the clearance is issued, the downstream D-side updates the electronic flight strips.

The second option is for the downstream D-side controller to wait until one or both have entered the downstream sector before taking action to resolve the conflict. The downstream D-side, with the aid of a DST, would determine a resolution and coordinate with his/her R-side. The R-side would issue the clearance. The downstream D-side might choose this option if his/her workload is too high at the time of the initial conflict/spacing problem detection. Another reason the downstream D-side might choose to wait is if the aircraft are too close to the downstream sector boundary. In this case, there would not be enough time for the D-side to coordinate with the upstream controllers. Of course, for the Intra-sector conflict shown in case A of Figure 3, this is the only option that applies.

For upstream metering problems, the downstream D-side determines a solution that will nominally result in the aircraft meeting the required time of arrival. The D-side communicates this to the upstream D-side, who then coordinates with his/her R-side to have the clearance issued. For downstream metering, the downstream D-side determines a solution and coordinates with his/her R-side, who then issues the clearance.

Advantages

The sector where the predicted loss of separation/conformance occurs has the responsibility for resolving it. This is consistent with the fundamental training and culture of today's controllers. Lessons learned from URET Free Flight Phase 1 would be applicable. The implementation would be more evolutionary than all the other concepts to be discussed next.

Disadvantages

This concept requires continuous inter-sector coordination to be effective. In most situations, the downstream D-side would be required to coordinate with at least one upstream controller. If an upstream R-side were involved with higher priorities (e.g., tactical conflicts), then the downstream D-side would need to postpone the resolution until the R-side became available. For strategic planning purposes, this could be an ineffective strategy.

Another disadvantage to this downstream concept is that bottlenecks in traffic flow could result for sectors subject to traffic management constraints. It appears likely that D-side coordination with upstream sectors will be only partially effective in maneuvering traffic to meet a metering constraint in an arrival sector. As a result, the R-side controller working the arrival sector must maneuver many of the aircraft tactically to meet the metering constraints (a relatively inefficient and workload intensive approach that is contrary to the goals of trajectory orientation). Such a tactical approach also reduces the effective performance of CDR tools due to the lack of intent knowledge.

Another disadvantage relates to the today's sector team concept. The R-side is the team leader and in many cases the D-side position is filled by less experienced and/or less skilled personnel. Coordination efforts by the D-side during peak traffic periods might be denied by the R-side when his/her workload is high. A better strategy would be one where strategic planning is initiated by the R-side.

7.2 Candidate 2 EUROCONTROL PHARE

This candidate concept represents trajectory negotiation roles defined for the Program for Harmonised ATM Research (PHARE) in EUROCONTROL demonstration (PD/3) (References 26-27). In this concept, the downstream D-side strategically plans the upstream using a DST as configured in Candidate 1. The D-side issues the resolution advisories to one or both aircraft via CPDLC rather than voice communication. The advisory involves planned changes to the flight path that become effective at the downstream sector boundary. The advisory could require the pilot to change the aircraft speed, heading or altitude (or combination thereof) prior to entering the downstream sector, but after the handoff. Tactical conflicts would still be the responsibility of the downstream R-side.

Advantages

This concept does not require the downstream D-side to coordinate resolutions with upstream sectors to implement the advisories, reducing the workload of both positions (related to such coordination, but not necessarily a reduction in total workload). Also, the downstream D-side would not need to coordinate with his/her R-side, assuming that the resolution is not of a tactical nature. (i.e., the situation would look no different to the downstream R-side than if the flight plan had been changed by the upstream sector) The D-side would perform strategic planning in a somewhat autonomous environment, allowing his/her attention to focus on achieving the "best" resolutions possible. The term "best" is subjective, depending on the specific goals of the sector team at a given time. In the busiest periods, it might imply orchestrating the traffic flow in patterns that are preferred by the R-side. At other times, it might be an indication to minimize aircraft deviations or maximize flow rate conformance. This D-side freedom to decide afforded by the autonomy would not be present in the Candidate 1 concept.

Disadvantages

As mentioned in the SOW, the resolution can become obsolete if the upstream R-side issues a flight path change to the aircraft (e.g., to meet a requirement in a SOP) after the downstream D-side has issued the strategic clearance via CPDLC. This causes a problem because the original DST downstream resolution was based on the assumption that the aircraft would follow the original flight plan until the sector boundary. For example, consider a downstream D-side issuing a strategic clearance to an upstream aircraft to avoid a conflict with another aircraft 18 minutes out. A couple minutes later, the pilot requests a speed reduction due to turbulence. The upstream R-side grants the request. Ten minutes later, the aircraft reaches the sector boundary and is no longer experiencing turbulence. The aircraft performs the required speed, heading and altitude changes from the CPDLC clearance. However, to reach the downstream sector boundary has taken 30 seconds longer than predicted by the DST. These 30 seconds correspond to 4 nm and would result in a conflict in six minutes with the original aircraft that the CPDLC clearance was intended to resolve.

Another disadvantage is the downstream D-side will have to refocus his/her attention on the aircraft during the sector transition, after having spent some amount of time on other tasks, to ensure that the aircraft complies with the clearance. Controllers would rather issue a clearance and immediately monitor for compliance.

One way to address these two concerns is for the downstream D-side to plan his/her tasks so that the conflict resolution is calculated and the clearance is issued just prior to the aircraft reaching the sector boundary. This would work best in the situations where only one aircraft is maneuvered since the probability is small that both aircraft in the conflict pair reach the boundary around the same time. For metering/spacing, however, waiting for the sector boundary to initiate the maneuvers shortens the effective time horizon, which in turn, makes speed reduction a less feasible option. (Speed reduction is a good technique for absorbing delays because it is fuel efficient and results in a simpler clearance instruction for the controller.)

7.3 Candidate 3 Upstream D-side

This concept, (as well as candidate 4) can be distinguished by the characteristic that the sector that “owns” an aircraft also “owns” the pending downstream conflict/spacing/metering problem and thus is required to determine a solution. The upstream D-side strategically plans the downstream. The DST is configured so that predicted problems are displayed to the sector that currently "owns" the aircraft involved in a conformance problem and/or conflict. For example, upstream metering problems would be displayed to the upstream D-side position to determine a delay strategy. Likewise, an Inter-sector conflict and/or spacing problem would be displayed to the upstream D-side positions in Sectors 1 & 4. The External Intruder conflict/spacing problem would be displayed to both the downstream D-side in Sector 2 and the upstream D-side in Sector 4. In both these cases, the D-side positions would need to coordinate to determine if one or both aircraft need maneuvering. The Intra-sector and External conflicts could be resolved by the D-side without inter-sector coordination. For all scenarios, the R-side who currently “owns” the aircraft issues the clearance. The D-side monitors for compliance and, using a DST, ensures that no new problems result from the maneuvers. To avoid interfering with the downstream controllers situation awareness, some procedures should be developed that prohibit the upstream controllers to maneuver aircraft at a to-be-determined amount of time prior to reaching the sector boundary.

With some modifications to the configuration of the DST, this concept has further potential for reducing inter-sector coordination. For Inter-sector conflicts/spacing problems, the DST could be configured so that of the two upstream D-side positions that own the aircraft in conflict, only one position is notified initially (similar to the AERA 2 concept). If the problem is not resolved within a certain amount of time, then the problem is displayed to the other upstream D-side as well for possible strategic planning.

For spacing problems, the logic to determine which sector to notify could be based on which aircraft needs to be delayed (relative to the other aircraft). The sector that owns the aircraft requiring delay should be the sector notified by the DST.

For conflicts, the logic could be based on predictions of workload indicator and/or the elapsed time prior to reaching a sector boundary. For an External Intruder conflict, notifying only the D-side of the sector where the conflict is predicted to occur (the downstream D-side in this case) may be a good option since the downstream R-side "owns" the conflict and would have the strongest justification for leading its resolution anyway. In other words, since the downstream R-side would ultimately want the resolution in a way most appropriate to his/her preferences, there is no reason to involve the upstream sector of the conflict (unless the downstream was busy with other tasks).

Advantages

This concept would not result in the bottlenecks mentioned in Candidate 1 for sectors with traffic management constraints because the upstream would be responsible for meeting downstream constraints. In addition, this concept requires less inter-sector coordination than Candidate 1. If the DST could be configured as suggested above, this would reduce inter-sector coordination and minimize workload for the four problem types in Figure 6. (Some type of coordination would still be required for problems occurring near sector boundaries.)

Another advantage is the maneuvers can take place immediately upon issue of the clearance. This is a significant benefit in terms of efficiency over Candidate 2 for large delays to meet metering/spacing constraints and essentially makes obsoleteness of the clearance a non-issue.

Another advantage, which applies to External conflicts only, is that this concept is consistent with current controller responsibilities. In 7110.65, the section on Control Transfer states, "Transfer control of an aircraft only after eliminating any potential conflict with other aircraft for which you have separation responsibility." Of course, a DST capability, as envisioned for EDA and AERA 2, can determine a "potential conflict" for much longer time horizons than possible today.

Lastly, this concept requires continuous intra-sector coordination, which could increase the situation awareness of the team and also promote the "team concept" that some controllers feel is lacking in today's environment. However, depending on the individual personalities of the sector team, this could also be a drawback. The D-side position does not have the autonomy as mentioned in Candidate 2, so the D-side goal of strategic planning is dependent on the R-side "buying in" to it. This dilemma is analogous to the previous generation of cockpit roles/responsibilities/procedures (between caption and co-pilot) prior to the more recent changes associated with the modern Crew Resource Management (CRM) concept. A similar concept could be employed for sector teams as well.

Disadvantages
For Inter-sector conflicts, this concept is not consistent with the tactical mentality engrained in controllers today. The upstream controllers would most likely not even consider resolving Inter-sector conflicts (although they might notify the downstream controller about potential problems coming their way) because they are trained to solve problems first and foremost in their own sectors. Based on the controller interviews, this perceived problem might diminish over time. For example, if controllers collectively resolved downstream conflict/spacing/metering problems in a strategic manner, they would most likely see a reduction in tactical conflicts and flow-rate conformance problems. The reduced workload associated with fewer tactical problems and the DST capability for predicting Inter-sector conflicts, as well as controller pride in their work, may provide much of the impetus needed for controllers to accept this new role.

7.4 Candidate 4 Upstream R-side

This concept is similar to Candidate 3, but the upstream R-side, rather than the upstream D-side, is responsible for strategic planning of the downstream. DST advisories are integrated and blended into the R-side's primary traffic display. The DST is configured so that predicted problems are displayed to the sector that currently "owns" the aircraft involved in the problem. The upstream R-side also monitors the tactical situation, issues all required clearances to "owned" aircraft, and monitors the cleared aircraft for compliance.

The upstream D-side assists the R-side with strategic planning, which includes inter-sector coordination with other upstream controllers that would be needed for Case D of Figure 3. In addition, the D-side assists in monitoring the tactical situation and maintains the DST model of intent.

Advantages
The advantages of Candidate 3 also apply.

In addition, this concept requires less intra-sector coordination than Candidate 3 because the R-side can issue strategic clearances directly. The role of the R-side as the team leader is consistent with today's roles (see Candidate 1 disadvantages).

Disadvantages
The disadvantages of Candidate 3 also apply.

In addition, the workload of the R-side will need to be assessed because this concept basically requires the R-side to perform all the tasks he/she does today in addition to the new task of strategic planning enabled by DST technology. This concern is somewhat diminished by the impact that trajectory orientation is expected to have in reducing the frequency and extent of tactical problems to be solved. In terms of R-side sector workload, by resolving problems in a strategic manner, the controllers in adjacent sectors would most likely see a significant reduction in tactical conflicts. If all sectors participate in strategic planning, there should be a net reduction in tactical conflicts. The hypothesis is that the additional workload incurred by strategic planning is offset by the reduction in workload due to fewer tactical conflicts. Of course, the usability and reliability of the DST will be critical in accounting for this trade-off.

7.5 Candidate 5 Eurocontrol MSP

This candidate is based in part on the EUROCONTROL concept that proposes a new Multi-Sector Planner (MSP) position (References 26-27). The EUROCONTROL MSP concept combines functions that have traditionally been in the domain of controllers (e.g., trajectory planning) with functions that have traditionally been in the domain of traffic management in the USA (i.e., flow control). However, for the purposes of this study, the MSP candidate concept represents only one aspect of the full EUROCONTROL MSP concept (i.e. that aspect related to the planning, and contracting of user-ATM negotiated trajectories). The reference is made here to credit MSP proponents for inspiring the inter-sector coordination aspect evaluated in this study.

Each MSP monitors a group of sectors within a Center. The number of MSPs per Center will depend on traffic density and other criteria to be determined. The MSP is responsible for strategic planning of aircraft within his/her defined airspace. The MSP issues clearances based on advisories from the DST via CPDLC that become effective at the boundary of the next sector. The MSP is responsible for monitoring of compliance.

Advantages

Like Candidate 2, this concept requires minimal inter-sector coordination, if any. By limiting flight plan changes to ones that are initiated after the next-sector's boundary, this concept does not require the MSP to coordinate with the current sector to issue a clearance. From the perspective of the next downstream sector, the MSP change simply appears as the current flight plan when the flight comes under that sector's control. The MSP effectively "inserts" the flight plan update in between the two sectors. In this way, the MSP position is autonomous, which will permit him/her to focus specifically on achieving a trajectory orientation.

Disadvantages

On the surface, this concept appears to be the best candidate for achieving a trajectory orientation. However, there are several issues that were identified in the assessment worth discussing. To begin with, there is a risk that the effectiveness of the MSP position at the busiest Centers would be limited during peak periods of traffic – a time when trajectory orientation is most needed. The risk is related to the number of sectors the MSP must serve. This issue may be answered through controller-in-the-loop simulation. Reducing the number of sectors per MSP position to improve efficiency could result in diminishing returns when compared to the other sector-based candidate concepts.

Second, since the resolution becomes effective at the sector boundary, it can become obsolete if the upstream R-side issues a tactical clearance to the aircraft after the MSP has issued the strategic clearance via CPDLC. This causes a problem because the DST resolution is based on the assumption that the aircraft would follow the original flight plan until the sector boundary.

In addition, it is necessary that the MSP work seamlessly with the controllers/sectors in his/her jurisdiction. Otherwise, controllers would be very resistant to what they might view as outside interference with their basic roles and responsibilities. A strong understanding of the operations and traffic flow of all sectors in his/her domain is necessary to avoid impeding the actions of the controllers in those sectors. The controllers expressed the opinion that the MSP position would require a controller who is highly skilled and well respected amongst his/her peers. Otherwise, it is unlikely that the concept would be effective in achieving a trajectory orientation.

The MSP also would have authority to issue clearances, but whether he/she should be responsible for an operational error (i.e., violation of the 5 nm standard) needs to be determined. For example, the MSP might fail to adequately monitor for compliance of a strategic clearance that results in a tactical operational error. Who is responsible for the error, the MSP or R-side controller who “owns” the aircraft at the time of the operational error? Operational acceptance of this concept requires answers to these questions.

7.6 Candidate 6 NASA Airspace Coordinator

This candidate represents the NASA Airspace Tool concept (reference 25) of creating a new position called the Airspace Coordinator (AC). (For the purpose of maintaining consistency between the other candidate concepts, the assumption is made that the DST available to the AC has EDA-like functionality rather than functionality envisioned in the original Airspace Tool concept.) The AC sees the airspace of many sectors within a Center. The AC, assisted with a DST, is able to provide more intelligent solutions for efficient air traffic management than a single controller assisted by DST capability at the sector. This concept has many similarities to Candidate 5. The only significant difference between the two concepts is the method for issuing the strategic clearances. In this concept, the AC resolves the conflict with the aid of the DST, but he/she must coordinate with the R-side, via the scope interface, for agreement. Upon agreement, the R-side issues the clearance and is responsible for monitoring for compliance. As such, unlike Candidate 5, the R-side is also clearly responsible for any operational errors that may occur.

Advantages
Like the MSP in Candidate 5, this concept allows the AC position to have a complete picture of the Center traffic flow. For a sector controller who is experiencing high aircraft density and workload, this will enable the AC to reduce the controllers workload by strategically planning upstream aircraft so that the trajectories are conflict-free prior to entering the congested sector.

Unlike the MSP concept, the maneuvers can be initiated upon receipt of the clearance and it would be less likely that the clearances would become obsolete.

Disadvantages
This concept requires coordination for all conflicts. The AC would be required to coordinate with at least one R-side controller per conflict and would not be as autonomous as the MSP in Candidate 5. If the R-side were involved with higher priorities (e.g., tactical conflicts), then the AC would need to postpone the resolution until the R-side became available. For strategic planning purposes, this could be an ineffective strategy.

Since the R-side would not have access to a DST, a method to make the R-side aware of the intent of the AC must be developed so that tactical actions of the R-side do not negate the strategic intentions of the AC.

7.7 Candidate 7 Upstream Team

This concept was based on the suggestion from controllers at the Denver Center to combine the Upstream D-side (Candidate 3) and Upstream R-side (Candidate 4) concepts. It is important to note that this concept is very similar to the AERA 2 operational concept. AERA 2 also proposed an upstream team, but there was no clear delineation between R-side and D-side roles.

Candidates 3 & 4 shared a common characteristic favored by the controllers, namely that the upstream sector resolves downstream problems. This minimizes inter-sector coordination compared to some of the other concepts and would allow controllers to be more focused on strategic planning. The controllers disliked the aspect of the Upstream D-side characteristic that only the D-side controller would have access to EDA-like decision support. From a workstation perspective, they thought it would be most efficient to have both R-side and D-side positions supported by the decision support capabilities. Certainly this would be more convenient for the R-side if he/she was the only controller working a sector during slower periods of air traffic. On the other hand, the primary drawback of the Upstream R-side candidate, based on controller feedback, was its heavy dependence on the R-side position to support strategic planning tasks during busy periods (a time when the R-side is already experiencing high workload). This dependence may or may not inhibit a trajectory orientation during periods when it is needed most.

In the Upstream Team concept, both the R-side and D-side are supported by EDA-like capability. The R-side would manage all tactical conflicts, and as the team leader, delegate strategic problems to the D-side depending on workload and other circumstances. If the R-side was too busy with tactical situations, the D-side would work alone on strategic planning, otherwise the strategic planning would be shared between both positions. Until CPDLC becomes available, the R-side must concur with the D-side resolution. Prior to the availability of CPDLC, the R-side would be responsible for issuing clearances to implement the strategic plans. With CPDLC, the R-side would have the option to delegate clearance communications to the D-side position as appropriate. This approach maximizes a controller team's flexibility to manage their traffic and workload. If the sector team includes a new controller to be checked out, the R-side team leader could require concurrence with D-side resolutions prior to D-side issuance of clearances. This provides a method for the more experienced controllers to supervise and mentor the less experienced with minimal risk (analogous to what occurs in a flight deck between a senior captain and a junior first officer). With or without CPDLC, the controller who resolves the conflict is responsible for monitoring the aircraft for compliance (e.g., if the R-side issues the clearance, the R-side must monitor for compliance).

As in Candidate 3 and 4, this concept can reduce inter-sector coordination if the supporting DST technology is configured to distribute problem alerts/advisories to a single sector.

Advantages
The advantages listed in Candidate 3 apply here as well.

By having EDA-like DST capabilities available to both controllers, this team concept appears to be the most effective of all the concepts for consistently supporting strategic planning. As stated before, strategic trajectory planning is the single most important criteria for achieving a trajectory orientation. The team concept allows for a balancing of workload between the R-side and D-side positions. If the R-side is not too busy with tactical situations, both controllers can work on aircraft conflicts further out on the time horizon, possibly to 20 minutes out. In contrast, if the R-side was busy with tactical situations, the D-side would perform all the strategic planning, but perhaps only work on problems with time horizons of 10-15 minutes out. This concept has a natural ebb and flow that should work well to smooth out the conflicts for air traffic patterns that have their own peaks and troughs.

Disadvantages
The most significant disadvantage (as is true for Candidates 3 & 4 as well) is the risk associated with implementing Upstream-Team based procedures. The operational viability of this concept rests on the dependence between sectors to receive traffic flows that are nominally planned to be in conformance with ATC constraints. Like posts supporting a picket fence, each post must carry its weight. Each downstream sector is, in turn, an upstream sector to someone else. The added workload to plan nominal conformance upstream translates into a lower workload in the next sector. Assuming that the net workload remained constant, but was redistributed, the airspace would benefit from a more predictable and robust flow of traffic. In any case, most if not all sectors must adopt the practice to realize the net benefit.

Another disadvantage to this concept is the need to provide EDA-like DST capabilities for both controller positions at each sector.

7.8 Candidate summary and down-selection

One of the goals of this research was to determine which candidate operational concepts have the highest potential of achieving a trajectory orientation. This results of this research will lead to more focused evaluations via high-fidelity controller-in-the-loop simulation. Table 2 presents a comparative summary of the seven concepts that were evaluated. For each of the seven concepts, a side-by-side comparison of the controller position responsible for each of the controller activities necessary for strategic flow-rate conformance and conflict resolution is listed.

Table 2
Candidate Concept Comparison

Candidate Concept		1 URET	2 EURO CONTROL PHARE	3 Upstream D-side	4 Upstream R-side	5 EURO CONTROL MSP	6 NASA AC	7** Upstream Team
Position responsible for planning strategic resolution		Down stream D-side	Down stream D-side	Upstream D-side	Upstream R-side	MSP	AC	Either Upstream position
Position responsible for coordination		Down stream D-side	Down stream D-side	Upstream D-side	Upstream D-side	N/A	AC	Upstream D-side
Position responsible for issuing strategic clearance and monitoring for compliance		Upstream R-side	Down stream D-side	Upstream R-side	Upstream R-side	MSP	Upstream R-side	Either Upstream Position
Strategic clearance becomes effective where/when?		Upon issue	Sector boundary	Upon issue	Upon issue	Sector boundary	Upon issue	Upon issue
Maintains model of intent		Down stream D-side	Down stream D-side	Upstream D-side	Upstream D-side	MSP	AC	Upstream D-side
Strategic planning coordination required between R-side and D-side position?*	Intra-sector	Yes	Yes	Yes	No	N/A	N/A	No
	External	No	No	Yes	No	N/A	N/A	No
	External Intruder	Yes	Yes	Yes	Yes	N/A	N/A	No
	Inter-sector	No	No	Yes	Yes	N/A	N/A	No
Number of sectors that require coordination* (Sectors adjacent to the sector responsible for strategic planning)	Intra-sector	0	0	0	0	N/A	1	0
	External	1	0	0	0	0	1	0
	External Intruder	1	0	1	1	0	2	1
	Inter-sector	2	0	1	1	0	2	1

* For the purposes of comparison, the assumption is made that both aircraft will be issued resolution advisories. In many cases, the controller may choose to focus on one aircraft, which would reduce the coordination that is indicated by this table.

** Assumes CPDLC is available

One of the specific goals of RTO-34 was to down-select from the eight candidate concepts to four. Likewise, one of the specific goals of RTO-34B was to down-select from four concepts to two. In general, the controller interviews indicated that the operational concepts that required significant inter-sector coordination were least likely to be effective in achieving a trajectory orientation because of the different prioritization of tasks that would inhibit the R-side from being fully effective in issuing strategic clearances in a timely fashion. Because of this, the first round down selection criteria was based partly on the amount of inter-sector coordination required between the strategic controller and the R-side position that would issue the clearance. As such, the Candidates 1 (URET-like procedures) and 6 (NASA AC) were not selected

On the other hand, Candidates 3 (Upstream D-side) and 4 (Upstream R-side) were not selected, in favor of Candidate 7 (Upstream Team), because Candidate 7 combined the best features of both with few of the disadvantages of either. By process of elimination, the field of eight was reduced to three (instead of four as originally intended). Candidate 2, the PHARE concept, Candidate 5, the MSP concept, and Candidate 7, the Upstream Team concept, were down-selected for further evaluation during RTO-34B. There did not appear to be a strong reason to re-consider a fourth candidate for evaluation so the field remained at three.

Upstream Team vs. PHARE and MSP

There are three advantages of the Upstream Team over PHARE and MSP. The first advantage is that the Upstream Team concept enables resolutions to become effective immediately so that delays for flow-rate conformance are more efficient (longer time horizons for speed control). PHARE and MSP are restricted to flight plan changes that are initiated at the boundary to the next sector. Second, PHARE and MSP resolutions could become obsolete if the upstream controller issues a clearance to the aircraft prior to departing the upstream sector. Third, the Upstream Team is more robust to the elemental changes that the ATC system will experience during the evolution to Free Flight. For example, it is not dependent on CPDLC. In contrast, PHARE and MSP require CPDLC. In the Upstream Team concept, aircraft can be strategically planned whether or not they are equipped with CPDLC (although it is expected that the concept will be more efficient with CPDLC than without).

There is one major disadvantage to the Upstream Team compared to the other two concepts. The transition to upstream-based procedures has significant risk since it requires that the en route controllers in the US and the union that represents them support the shift in responsibility that permits upstream controllers to resolve downstream problems. In contrast, PHARE and MSP circumvent the issue of ownership by avoiding upstream responsibility of downstream problems. If the upstream-based procedures become realizable, it is expected that the payoff, in terms of the number of aircraft achieving a trajectory orientation, will be much higher than the other two concepts.

MSP vs. Upstream Team and PHARE

The MSP concept offers one significant advantage over the PHARE and Upstream Team. The MSP concept creates an autonomous position that can focus specifically on strategic planning. This enables the MSP position to be introduced with minimal change to today’s sector roles and responsibilities. The other two concepts must provide tactical planning as a first priority so strategic plans might not always get formulated.

PHARE vs. Upstream Team and MSP

To complete the comparison, PHARE does not appear to have any significant advantage over the MSP or the Upstream Team concept. Based on the advantages of the MSP and Upstream Team concept compared to PHARE, PHARE was not selected for further research at this time.

Upstream Team vs. MSP

Although one of the goals for RTO-34B was to down select to two concepts, because of the need to prioritize future research, it was necessary to make a final selection between the Upstream

Team and MSP concepts. The Upstream Team concept was selected for more detailed research for the following reasons:

1. EUROCONTROL research related to the MSP concept can be leveraged while NASA continues to explore the feasibility of the Upstream Team concept in greater detail
2. The R-side and D-side positions within the Upstream Team more closely resemble the sector teams in place today at the en route Centers
3. The Upstream Team approach to trajectory-oriented planning is expected to be more effective and efficient

8 DST Capability and Usability

Accurate trajectory synthesis is the key feature that enables accurate resolutions of conflicts and flow-rate conformance problems. Accurately predicting trajectories 20 minutes into the future requires unique DST capabilities. In addition, since the focus of the DST is human-centered automation, usability issues are also of great importance. The goal of this section is to identify DST capability and usability requirements to be included in the software design of the DST.

8.1 Modeling Intent

One of the primary requirements of the DST is the ability to model the intentions of controllers and pilots over the DST's prediction time horizon. Without this capability, the probing function that determines if an aircraft's current flight plan or trial plan is conflict-free and conforming to flow-rate constraints would be inaccurate in its prediction. This could result in unnecessary actions by controllers to correct problems that do not exist. Alternatively, real problems could go undetected for a significant amount of time, which is particularly inefficient for absorbing large delays.

One of the challenges in modeling intent will be the design of the user interface that places amended flight plan information into the system. (System here is defined here somewhat generically to include DST support for adjacent sectors. The issue of DST integration with HOST is beyond the scope of this research.) It is imperative that the interface allow for quick entries of information by the controllers so that they keep the flight plans updated whenever a change in intent is noted. At the same time, the interface must not significantly increase their perceived or actual workload. As mentioned earlier, for trajectory-oriented strategic planning to be fully effective, all controllers must buy in to the approach. This entails maintaining updated intent information during the busiest traffic periods.

All the commonly used actions by controllers and pilots that result in changes to the nominal flight plan would be entered into the system through easily accessed interface entry options. Examples of intent choices (e.g., via a pull-down menu) are listed below:

- "Direct to" – allows aircraft to fly from current position to a downstream fix, airport, etc.
- Path-stretch/S-turns – allows aircraft to fly prescribed maneuver for prescribed time.

- Air hold – allows aircraft to be place into a holding pattern at the current location. This would effectively “pause” the trajectory synthesis predictions until the aircraft was released from the hold. An alert of a potential conflict should be signaled for any other aircraft that is predicted to pass near the oval-shaped airspace of the holding aircraft
- Release air hold – allows aircraft to be released from hold and resume original flight plan
- Change in airway – allows aircraft to switch from current airway to another airway at the next shared intersection
- Ignore crossing restriction – allows aircraft to maintain current speed/altitude despite an active crossing restriction requirement that is in effect.
- Modify crossing restriction – allows aircraft to meet a modified crossing restriction requirement (e.g., meets the nominal altitude, but at a faster speed)
- Climb/descend immediately – allows aircraft to climb/descend to specified altitude
- Climb/descend at specified fix – allows aircraft to climb/descend to specified altitude at specified fix
- Increase/reduce speed immediately – allows aircraft to immediately increase/reduce speed as specified

8.2 Capability/Usability

Conflict detection/resolution capabilities and the associated interfaces should be fully configurable by the controller so that preferences can be set and saved. Some examples of preferences that controllers requested:

- Detection time horizon for conflicts should be adjustable in the range of 5-20 min
- Detection time horizon for flow-rate conformance problems should be adjustable in the range of 5-20 min
- Resolution time horizon for conflicts should be adjustable in the range of 5-20 min
- Resolution time horizon for flow-rate conformance problems should be adjustable in the range of 5-20 min
- Separation minima that will signal an alert should be adjustable in the range of 5-15 nm

9 Conclusion

Trajectory orientation is a concept that, coupled with advanced en route DST capabilities, enables controllers to facilitate fuel-efficient, conflict-free trajectories across several sectors of airspace while conforming to flow-rate constraints. An operations assessment identified core issues in today’s en route operations that inhibit a trajectory orientation. In addition, seven operational concepts for new controller roles, responsibilities and procedures were evaluated for their potential in achieving a trajectory orientation. Two concepts, one inspired by the EUROCONTROL MSP concept and one based on the Upstream Team concept, were determined to be most likely candidates for achieving a trajectory orientation.

Further research will focus on formulating tasks, roles, responsibilities, and procedures for the Upstream Team concept. Both R-side and D-side positions will be supported by EDA and work as a team to strategically plan trajectories across sectors. The task and procedures will be translated into a human performance model to simulate the Upstream Team concept. One specific goal of the modeling the Upstream Team is to validate the workload distribution theory that was hypothesized in this research, namely that workload will be more evenly distributed from congested downstream sectors to sectors further upstream. Collaboration is also in progress with the FAA Technical Center on experiments that will evaluate new candidate sector team configurations. The author is hopeful that an upstream-based concept can be added to the experimental candidates.

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